The Hawaii Stream Bioassessment Protocol
Version 3.01

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PREFACE

This manual provides technical details for Version 3.01 of the Hawaii Stream Bioassessment Protocol (HSBP) a "first generation" methodology for assessment and monitoring of Hawaiian streams utilizing a standardized "multimetric" approach. Through widespread application and continuous refinement of the HSBP, I hope to improve on its ability to provide biological insight into the health of Hawaii's streams within the context of assessing human-induced impacts. Emphasis placed on the linking of stream assessment data to the Geographical Information System (GIS) is intended to provide managers with a working platform for information analysis in water resource planning and management applications.

The underlying purpose for developing the HSBP is to provide the tools and informational framework required to conduct meaningful water quality assessments aimed at restoring and/or maintaining the "biological integrity" of Hawaii's streams. The term "biological or biotic integrity" as applied to stream ecosystems is defined as " the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley's 1981). This purpose aligns with the primary objective of the National Clean Water Act of 1987 (U.S. Gov. Print. Off. 1988), that is to "restore and maintain the chemical, physical, and biological integrity of the nation's waters" which is consistent with language in the Hawaii State Water Code for "…the protection and procreation of fish and wildlife and the preservation and enhancement of waters of the State…" (Final Report, Review Commission on the State Water Code 1995, LRB 95-0309-3).

The HSBP relies on biological measurements in order to evaluate the overall condition of streams; however, it should be noted that the chemical and physical properties of streams are also important attributes of water quality. To relate biological properties to water resource management, biological criteria (or biocriteria) are used which are "numeric values or narrative expressions that describe the preferred biological condition of aquatic communities based on designated reference sites (Barbour and Karr 1996). For Hawaiian streams, the condition of the native aquatic macrofaunal communities found at these reference sites "are used to help detect both the causes and levels of risk to biological integrity at other sites in the same region" (Barbour and Karr 1996). Further development of the HSBP may result in the inclusion of algal and invertebrate metrics which will provide even greater sensitivity to levels of human-induced environmental impacts to Hawaii's streams.

ACKNOWLEDGMENTS

TABLE OF CONTENTS   **PAGE**

MULTIMETRIC APPROACH AND REFERENCE CONDITIONS

Multimetric biological indices used to assess the health of streams have been compared to economic indices that evaluate the condition of the national economy (Karr 1997). Both integrate multiple measures and tests that evaluate specific aspects of the functioning and overall health of the system of interest. The first use of a multimetric approach in stream bioassessment can be credited to Karr (1981) who developed an "index of biological integrity (IBI)" based upon fish assemblage attributes. Since that time, the IBI has become a highly refined, well-tested and widely used tool for monitoring the health of the nation's rivers and streams. Fish (eg. Lyons et al. 1996) and invertebrate assemblages (eg. Kerans and Karr 1994) have been most commonly used in IBI's.

Key to the effectiveness of an IBI is the selection of the appropriate attributes (or metrics) that are targeted for measurement. According to Karr and Chu (1997), these metrics must: 1) integrate meaningful ecological information with regard to the manner in which aquatic organisms respond to human influence of their environment; 2) be sensitive to stressors of aquatic systems and; 3) be relatively easy to measure and interpret. The most successful metrics integrate information from the individual, population, community, and ecosystem levels of organization. IBI metrics may choose to incorporate information related to taxa richness, sensitive species, individual condition, etc. Scores obtained for these metrics are then combined into "a single, ecologically-based index of water resource quality" (Karr 1997), the "IBI".

The multimetric approach has also been applied to an assessment of physical stream habitat condition that can "identify, estimate, or predict alterations due to anthropogenic or natural causes; identify limiting factors critical to target organisms; and facilitate the classification of streams" (Osborne et al. 1991). Simply stated, habitat metrics are aimed at assessing the conditions of the environment in terms of the support it provides for aquatic organisms. In general, the more natural and undisturbed the habitat, the more robust are populations of native organisms. The habitat metrics are sensitive to departures from "natural" conditions that may be induced by weather-related events (e.g. floods or landslides) but are more chronic and persistent when caused by human degradation (e.g. feral animal disturbance, land clearing, urban runoff, alien species introductions, etc.).

In order for the assessment indices to have practical relevance, however, a standard of expected biotic integrity and habitat condition is needed for comparisons of relative quality within- and among ecoregional streams. The concept of the "reference condition" provides such a standard and is a key element in stream monitoring and bioassessment programs of states as well as in EPA's efforts to define water quality through the use of formal biological criteria (biocriteria) (Barbour and Karr 1996). Recognizing that biologically pristine streams no longer exist, the reference condition is developed using sites on "minimally impacted" streams. Comparisons of quality can then be thought of as departures from those expected under reference conditions. For the purposes of the HSBP (Version 3.01), I have adopted the multimetric approach and developed expectations of biotic quality (i.e. the reference condition) based upon the results of sampling in Hawaii's most "pristine" streams.

THE HAWAII STREAM BIOASSESSMENT PROTOCOL (HSBP)
CONCEPTUAL FRAMEWORK

The HSBP (Version 3.01) utilizes sampling protocols for two integrated indices that evaluate the:

1. Biotic integrity of a particular stream site (the Hawaii Stream Index of Biotic Integrity (HS-IBI) and;
2. Condition of the supporting habitat for aquatic organisms (Stream Habitat Assessment).

The ecological habitat of stream organisms technically encompasses both physical and chemical qualities of the stream and adjacent vegetated areas (riparian zones) as well as species interactions occurring within the stream. We use Barbour et al.'s (1997) narrower definition of habitat as, "the quality of the instream and riparian (area) which influences the structure and function of the aquatic community of the stream." Ten key physical attributes of Hawaiian stream habitat are measured in the HSBP and scored for quality in terms of departures from reference conditions.

Classification

Classifying streams and stream habitats into a geographic, spatially nested hierarchy is a widely accepted approach used to account for physical habitat variability (Allen and Starr 1982). At the ecosystem level of classification we adopt the general scheme of Polhemius et al. (1992) for inland waters of tropical Pacific Islands. The HSBP (Version 3.01), therefore, only applies to "Perennial Continuous Streams" and of these streams only to;

1) terminal reach segments that do not have deep estuaries (ie. terminal waterways > 2 m depth) and to;
2) midreach segments as defined by Polhemius et al. (1992) only encompassing slope gradients < 30 %. Headwater reaches, deep estuaries, and upper segments of midreaches are therefore excluded from this treatment.

Little detailed work has been directed at further classification of mid- and terminal reaches in regards to variation in geomorphology and hydrology. The HSBP utilizes stream channel slope (i.e gradient) at the "channel unit" scale (Hawkins et al. 1993) as a mechanism for partitioning expected natural variability in stream habitat associated with elevation; however, a comprehensive hierarchical classification framework is still needed to group Hawaiian stream "systems" (Frissell et al. 1986) into similar entities (or clusters).

Channel Units and Stream Morphology

Native Hawaiian stream macrofaunal species are adapted to a set of naturally occurring attributes of physical habitat structure that are ecologically relevant. To provide a framework to quantify these attributes, I have attempted to simplify physical habitat variation into conspicuously visible "channel units". Hawkins et al. (1993) defines these as "quasi-discrete areas of relatively homogenous depth and flow that are bounded by sharp physical gradients". The pattern or morphology of channel units observed in a segment of stream is directly influenced by "channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load,

and sediment size (Leopold et al. 1964). Channel slope (the difference in water surface elevation per unit stream length) is regarded as the most important factor influencing bed features and stream morphology (Rosgen 1994).

Channel units are, therefore, regarded in the HSBP as standard measurable units of habitat that are separated spatially by conspicuous zones of transition (transition zones).

Changes or sequences of habitat types within channel units are governed by variation in slope gradient; therefore, transition zones are characterized by turbulent flow and obvious changes in elevation. In the HSBP these zones of transition are classified as "falls, cascades, chutes, and steps" (see Metric 1). Between these zones and within the channel units are found the various classes of "runs, pools, and riffles" (see Metric 1). Physical variation in the sequence of habitat and transition zone types along the stream continuum provides the natural heterogeneity that characterizes optimal physical habitat for native stream organisms. Negative human-induced influences to streams tend to reduce natural heterogeneity (i.e. optimal habitat) to the point where a single, homogenous habitat remains. Habitat degradation is accompanied by a decline in native aquatic species presence and altered community structure / function to the point where ultimately only alien species remain.

STREAM HABITAT ASSESSMENT
Assessment Protocol and Metrics

Ten metrics are utilized in the HSBP to assess the quality of stream habitat in terms of support provided for native aquatic organisms and expected response to human degradation (Table 1). The rationale and general application for each metric is explained individually in the sections that follow. The maximum possible score for a site is 200 points (20 points per metric) indicating attainment of the reference condition for habitat (i.e. 100 %) (Table 1). Application of the HSBP in the field has been designed to proceed in a logical series of steps that progressively yields data required to complete the entire assessment procedure. The protocol is explained in a general fashion in this section and detailed procedures provided later on. Electronic files for printing field datasheets, data summary sheets, and creating a records database are provided on the accompanying CD-ROM.

As a general explanation of procedure, the study reach (length determined as 20 times mean width; minimum length of 100 m) is visibly delineated through flagging into "reach quadrants" (ie. 0%, 25%, 50%, and 100% of study site length) (Fig. 1). Overall slope gradient from 0 % to 100 % elevation of the study site is used to partition natural variability; therefore, metrics may be scored using different sets of values (e.g. see Table 2a). Expectations of habitat quality are scaled for each quadrant and scores are determined as a percentage of optimal, suboptimal, marginal, and poor ratings of habitat attributes targeted by a particular metric. Measurement and quantification have been intentionally built into the scoring of metrics to reduce as much as possible observer bias and indecision over attribute values / qualities.
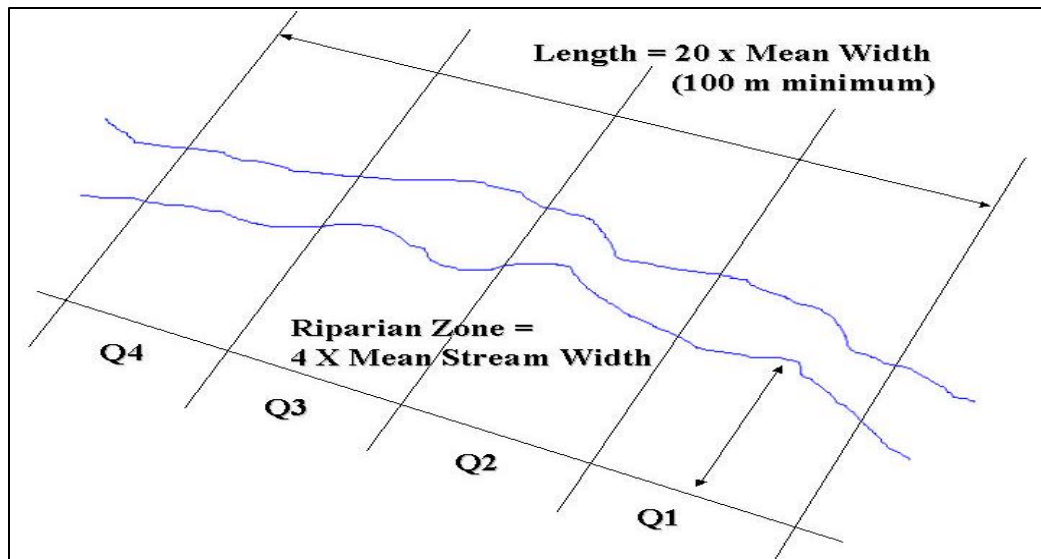
Figure 1. Quadrant framework for establishing stream assessment site in the HSBP.

Table 1. Habitat metrics for the HSBP, expected responses to human influence, and scoring.

Metric	Expected Response	Maximum Score
1. Habitat Availability	decrease	20
2. Substrate Embeddedness	increase	20
3. FPOM / CPOM Characterization	increase	20
4. Velocity-Depth Combinations	decrease	20
5. Channel Status	decrease	20
6. Channel Alteration	increase	20
7. Bank Stability	increase	20
8. Riparian Vegetation Zone Width	decrease	20
9. Percent Riparian Understory Coverage	decrease	20
10. Boulder / Cobble vs. Soil Presence	decrease	20
Maximum Possible Score		200

Metric 1. Habitat Availability

Within channel units, physical habitat for native stream organisms is created through dynamic interactions of stream flow with bed features such as substrate size, placement and composition. Channel slope (gradient) is the primary determinant of flow velocity ultimately governing plane view (e.g. pattern of meandering) and stream cross-sectional morphology (e.g. width and depth)(Rosgen 1994). For simplification, ten possible habitat types (Table 2a, b) are generalized under optimal natural conditions in Hawaiian streams. Observed or measured channel slope is used to partition expectations of habitat availability. Optimal conditions are created by heterogenous habitat that super-saturate the water with oxygen and provides access of stream organisms to a variety of habitat types and hydrologic regimes. Degradative human influences such as dewatering or sedimentation are expected to reduce natural habitat heterogeneity, degrade water quality, and reduce support for native stream organisms.

Table 2a. Expected Hawaiian stream habitat types partitioned by stream gradient.

Habitat Type	High Slope (> 10%) Cascades > 2 m in height	Medium Slope (5% - 9%) Cascades 0.25 m – 2 m in height	Low Slope (< 4%) Cascades < 0.25 m in height
Runs			
Exposed Boulder (EB)	X	X	X
No Exposed Boulder (NoEB)	X	X	X
Pools			
Scour	X		
Dammed	X	X	X
Riffles			
Exposed Boulder (EB)	X	X	X
No Exposed Boulder (NoEB)	X	X	X
Transition Zones			
Steps	X		
Chute	X	X	
Cascade	X	X	X
Falls (> 3.0 m height)	X		
Expected Habitat Types	5 minimum	4 minimum	3 minimum

Table 2b. Descriptions of expected Hawaiian stream habitat types.

Habitat Type	Water Depth	Description
Run NOEB	Moderate to Deep (>0.26 m)	Water flowing steadily in channel, little rippling at surface, with few or no boulders visible at surface; bedrock and/or cobble / boulder bottom.
Run EB	Moderate (0.26 m to 0.7 m)	Water flowing steadily in channel, little rippling at surface, many boulders visible at surface; bedrock and/or cobble / boulder bottom.
Riffle NOEB	Shallow (< 0.25 m)	Water rippling at surface; cobble dominant on bottom with few or no exposed boulder visible at surface.
Riffle EB	Shallow (0.25 m)	Water rippling at surface; cobble dominant on bottom with many exposed boulder visible at the surface.
Pool - Dam	Moderate to Deep (0.26 to 0.7 m)	Pool with bowl-shaped bottom; deepest point in center commonly bedrock; accumulation of cobble / boulder on downstream end; bedrock bottom.
Pool - Scour	Deep (> 0.7 m)	Pool below waterfall or high cascade; bowl-shaped bottom with deep point in center; bedrock bottom.
Trans Step	Moderate to Deep (0.26 m to 0.7 m)	Series of pools and large cascades forming a step in series; generally fast flowing meandering segment of stream; bedrock bottom.
Chute	Shallow to Moderate (< 0.5 m)	Stream narrows into confined channel; very fast flow; bedrock bottom no loose cobble.
Cascade	NA	Vertical fall of stream from 0.25 m to 2 m in height into a dam pool or forming splash zones on boulders.
Falls	NA	Vertical fall of stream > 2 m in height into a scour pool.

Each quadrant in the study site is scored for the number of observed habitat types and a total percentage of observed / expected (partitioned by slope category) is calculated for the entire study site (i.e. summing values for the four quadrants). This percentage is then used to determine

the appropriate point score for the metric. Maximum scores will be obtained if all quadrants meet expectations of available habitat types. The habitat availability score is expected to decline with increasing human influence (Table 1).

SCORING - PERCENT POSSIBLE HABITAT TYPES

Optimal					Suboptimal				Marginal					Poor				
100%	95	90	85	80	75 70 55	65	60		50	45	40	35	30	25	20	15	5	<2
20 pts	19	18	17	16	15 14 11	13	12		10	9	8	7	6	5	4	3	2	1

Metric 2. Substrate Embeddedness

Two generalized categories of substrate are most biologically active in Hawaiian streams in terms of supporting invertebrate and algal productivity (e.g. see Kido 1996c). "Stable substrate" (30 to 50 cm in longest length) is only disturbed during severe flooding while "movable substrate" (10 to 29 cm in longest length) (Kido 1996c) may be dislodged by moderate high-water approximating bank-full conditions. These two classes are readily identifiable in the field and overlap roughly with the "cobble" and "boulder" substrate size-classes of Cummins (1962). In natural streams systems, substrate particles are in constant motion downstream and are displaced according to size / weight in relation to flood flow velocity. Natural stream habitat is characterized by an abundance of maximally exposed cobble and boulder substrate.

Embededdness refers to the extent to which cobble / boulder substrate is covered or sunk into fine and coarse sediment on the stream bottom and can be evaluated in pool, riffle and / or run habitat types. Variation in the level of embeddedness is a result of large-scale movement and deposition of sediment coming from the watershed (Barbour et al. 1997). Such movement may be caused naturally (e.g. by landslides) but is most chronic, persistent, and damaging when induced by human activities that expose bare soil in watersheds. Displaced soil particles (< 2 mm diameter) make their way into the stream during periods of heavy rains burying cobble / boulder substrate and eliminating heterogenous habitat structure.

Optimal embededdness condition is characterized by the presence of limited quantities of sediment in which cobble / boulder substrate is freely exposed. This loose coarse substrate aggregate provides unobstructed interstitial spaces and microhabitat for organisms as well as greater surface area exposure for attachment of algae / periphyton. Highly sediment- and / or soil-buried substrate (poor ratings) resulting from excessive sediment erosion occurring in the watershed ultimately eliminates effective habitat for aquatic organisms. This metric, therefore, evaluates microhabitat availability and is sensitive to habitat degradation from landscape erosion and sedimentation. Embededdness from sediment particles is expected to increase with increased human-induced degradation in watershed and/or riparian areas (Table 1).

Optimal	Suboptimal	Marginal	Poor
Gravel, cobble, and boulder particles 0 - 10% surrounded by sediment	11 - 25 % surrounded by sediment	26 - 74 % surrounded by sediment	> 75 % surrounded by sediment

SCORING - EMBEDDEDNESS - PERCENT OPTIMAL-SUBOPTIMAL QUADRATS

Optimal					Suboptimal					Marginal					Poor				
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	5	<2
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

Metric 3. FPOM / CPOM Characterization

This metric compliments the Embededdness (Metric 2) and Substrate / Soil Presence characterization (Metric 10) evaluating the degree to which vegetative, land-derived organic matter covers the stream bottom. This decaying material is divided into Fine Particulate Organic Matter (FPOM)(particle size > .005 mm and < 1mm) and Coarse Particulate Organic Matter (CPOM)(particle size > 1mm)(Allan 1996) and can form a thick layer over the surface of the stream bottom blocking light penetration and smothering substrate under extreme conditions. FPOM / CPOM enter the stream vertically in closed canopy situations and laterally from riparian zones during periods of heavy rains and flooding (Kido 1999). Invasive alien tree species such as common guava, rose apple, and *hau* can take over large segments of stream riparian zones, shading the water's surface from light, depositing large quantities of plant and fruit material on the stream bottom. Natural hydrologic regimes tend to degrade, suspend and transport this material out of the watershed; therefore, naturally functioning streams do not allow this material to remain *in situ* for extended periods (Kido 1999). Human induced hydrologic disturbance (e.g. dewatering by water diversion), however, limits the stream's ability to remove FPOM / CPOM resulting in excessive accumulation on the stream bottom over time. This metric, therefore, not only evaluates the physical functional capability of the stream, but the influence of plant species in the riparian zone as well. FPOM / CPOM coverage on the stream bottom is expected to increase with human influence (Table 1).

Optimal	Suboptimal	Marginal	Poor
FPOM / CPOM localized, covering < 10 % of sq m quadrat;	FPOM / CPOM obvious, covering 11 - 25 % of sq m quadrat;	FPOM / CPOM widespread, covering 26 - 50 % of sq m quadrat;	FPOM / CPOM dominant covering >51% of sq m quadrat;

SCORING - SUBSTRATE CHARACTER - PERCENT OPTIMAL-SUBOPTIMAL QUADRATS

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Metric 4. Velocity-Depth Combinations

Heterogenous patterns of stream flow velocity and depth provide a mix of hydrologic regimes which create a variety of physical microhabitat for organisms and thus is an important feature of stream habitat diversity. These patterns are also important in driving physical functional processes such as stream oxygenation, organic matter transport, and nutrient delivery. Seven generalized combinations of velocity and depth are measurable in Hawaiian streams and can be readily identified with experience. As slope gradient is the most important determinant of pattern, observed or measured slope in the study site is used to partition natural variation and expected pattern (Table 3). Determinations / observations are made while traversing the entire length of the study site using periodic spot-checks of depth / velocity to verify decisions using a flow meter. The total observed flow regimes / expected flow regimes per quadrant (partitioned by slope) is

used to score this metric. Human-induced disturbance (e.g. diversion dewatering, channel alterations, etc.) will reduce / eliminate flow regimes, lower the numerical value of this metric, and degrade habitat for native aquatic species.

Table 3. Expected ranges of flow and depth in Hawaiian streams.

Flow Regime	Depth (meters)	Velocity (meters per sec)
slow flow-deep	> 0.71	< 0.20
slow-flow shallow	< 0.25	< 0.20
slow flow- intermediate depth	0.26 - 0.70	< 0.20
moderate flow- shallow	< 0.25	0.21 - 0.89
moderate flow- intermediate depth	0.26 - 0.70	0.21 - 0.89
fast flow- shallow	< 0.25	> 0.90
fast flow- intermediate depth	0.26 - 0.70	> 0.90
High-Medium Slope (5 to 30 %)	**six flow regimes expected per reach quadrant**	
Low Slope (< 4 %)	**four flow regimes expected per reach quadrant**	

SCORING - VELOCITY-DEPTH PER REACH QUADRANTS

High-Medium Slope (5 % to 30 %) (Cascades are > 0.5 m)

Optimal	Suboptimal	Marginal	Poor
At least 6 velocity-depth regimes present	Only 4 to 5 of the regimes present	Only 3 to 2 of the regimes present	Dominated by 1 velocity depth regime.

Low Slope (< 4 %) (Cascades < 0.5 m)

Optimal	Suboptimal	Marginal	Poor
At least 4 velocity-depth regimes present (no deep habitat)	Three velocity-depth regimes present	Two velocity-depth regimes present.	Dominated by 1 velocity-depth regime.

Points for velocity-depth combinations in total study reach (ie. all reach quadrants)

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Metric 5. Channel Flow Status

This habitat metric assesses the degree to which the stream channel is filled with water and is primarily aimed at evaluating aquatic habitat degradation due to stream diversion activities but is also useful for interpreting generalized hydrological conditions during different index periods or under abnormal flow regimes. Water diverted from the channel by dams and other obstructions, piped-diversions for irrigation, or drought will result in a loss of depth in the channel and a decrease in water level away from the banks. Under extreme low-flow conditions water may only be visible as a narrow ribbon in the lowest portion of the streambed. The channel will fill with water as flow increases reaching bankfull width or greater (i.e. water is at or higher than the

level of the bank) beginning at a minimum flood flow volume defined as 3 times median flow (Clausen and Briggs 1997).

An accurate determination of the level of water in stream channel is difficult requiring numerous cross-sectional measurements, definition of an "ordinary high water mark", and / or measured stream flow data over time. Therefore, the approach adopted in the HSBP is a qualitative one requiring the observer to estimate in a general way the extent to which the stream channel is filled with water. This task will require selection of an appropriate cross-sectional area of the study reach for observation characterized by a well-defined bank and
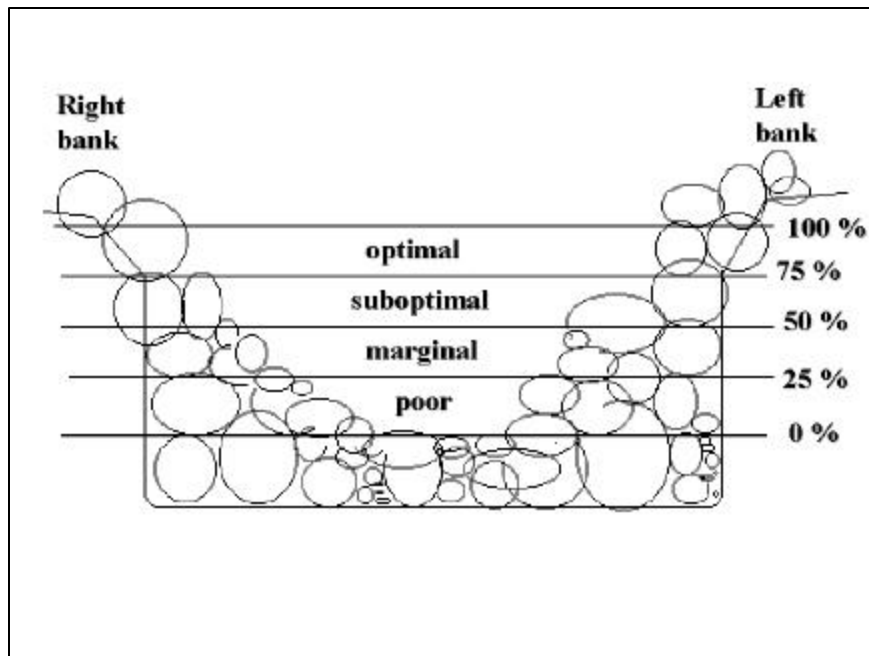
Figure 2. Schematic of theoretical application of channel flow status assessment metric.

U-shaped channel structure (Fig. 2). The extent to which water is flowing in the streambed, touching both banks, and filling the cross-section of the channel is evaluated on a scale from 0 (no flow) to 100 % (bank-full flow) is estimated according to the following table (Fig. 2).

Optimal	Suboptimal	Marginal	Poor
Water flowing in the channel touching both banks filling from 76 % to 100 % of cross-section.	Water flowing in the channel touching both banks filling from 51 % to 75 % of cross-section.	Water visibly flowing in the channel filling from 26 % to 50 % of the channel cross-section	No visible flow (0) or a narrow ribbon of flow in channel cross-section (25%)

SCORING - PERCENT OPTIMAL CHANNEL FLOW STATUS CROSS-SECTIONS

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Channel flow status is expected to degrade with increased human-induced influence as volume decreases and the stream pulls away from the banks (Table 1) (Fig. 2).

Metric 6. Channel Alteration

Human-induced alteration to the natural channel of streams (e.g. straightening or deepening) eliminates physical heterogeneity and destroys natural habitat important to aquatic organisms. Stream channels are typically altered for flood control purposes in Hawaii by leveling and lining the channel bottom with concrete (channelization). This eliminates the natural substrate-filled bottom characteristic of natural Hawaiian streams and can raise water temperatures to near lethal limits for native stream organisms during low flow periods. Channels may also be altered by invasive plants such as *hau* (*Hibiscus tiliaceus*) which can overgrow and alter the stream bottom with a dense cover of roots. To score this metric, linear measurements of disturbed channel length are made and used to calculate a ratio of disturbed reach length / total reach length. This percentage is used to score the "percent altered channel" which represents the degree to which the channel is channelized, dredged, or otherwise altered. Alternatively, the percent of altered channel per Quadrant can be estimated directly without a length measurement if desired. Optimal conditions are present when no alteration is present and percentage alteration increases with increasing human influence degradation (Table 1).

SCORING - PERCENT ALTERED CHANNEL

Optimal					Suboptimal					Marginal					Poor					
0%	2	4	6	8	10	13	16	19	21	24	29	34	39	44	49	59	69	79	89	100
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Metric 7. Bank Stability

This habitat metric evaluates the condition of the stream's banks for existing or potential soil erosion. Bank erosion deposits sediment into the stream eliminating natural habitat heterogeneity which is detrimental to stream organisms. Signs of bank erosion include exposed soil, unvegetated banks, sloughing, exposed roots, and/or muddy riparian conditions. Determinations are made through linear measurements of eroded-disturbed areas along right and left banks of the study reach. This measurement is used to calculate the ratio of eroded-disturbed bank length / total reach length yielding a percent eroded-disturbed value for each bank which is subsequently used for scoring. Alternatively, the percent of disturbed bank per Quadrant can be estimated directly without a length measurement if desired. Optimal habitat conditions exist when both banks are intact and show no signs of erosion. Human influence will tend to increase the percentage of disturbed bank (Table 1).

SCORING - PERCENT UNSTABLE BANK

Optimal					Suboptimal					Marginal					Poor					
Bank 0%	2	4	6	8	10	13	16	19	21	24	29	34	39	44	49	59	69	79	89	100
Pts 20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Metric 8. Riparian Vegetative Zone Width

Riparian zones stabilized by mature tree / shrub species retard landscape erosion, provide surface area for nutrient transfer to the stream, and act as buffers against pollutants entering the water. Intact riparian zones therefore support robust stream ecosystems. Riparian vegetation along Hawaiian streams generally consists of three components; 1) Trees; 2) shrubs 1 to 2 m in height; and 3) understory plants typically sprawling ferns and grasses. Metric 8 only scores the condition of trees and shrubs in the riparian zone (understory plant status is evaluated in Metric 9). Intact and functional riparian zones should have widths at least four times the mean width of the stream. Linear measurements are made of riparian zone width that attain optimal conditions (ie. 4X width) along the length of each of the four reach quadrants. The ratio of intact riparian length / total site length is calculated and used for scoring. Alternatively, the percent of the riparian area with intact vegetation per Quadrant can be estimated directly without a length measurement if desired. Optimal riparian habitat conditions have entirely intact tree and shrub zones on both banks. Increased human influence is expected to reduce the overall percentage of intact riparian zone (Table 1).

SCORING - RIPARIAN ZONE WIDTH

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Metric 9. Riparian Understory Coverage.

Riparian areas around streams may have intact tree and shrub components; however, understory plants may be sparse or absent due to feral animal damage, excessive runoff, and/or human-related activities. Certain alien tree species (e.g. common or strawberry guava) may also limit or eliminate understory growth. Lack of ground cover or understory plants will expose / loosen soil and become particularly severe in the case of animal-induced damage. These conditions will result in excessive soil erosion and soil movement into the stream thus degrading habitat for stream organisms. Vegetative protection is most critical within five meters of the water's edge. To score this metric, the linear length along both banks of intact "riparian understory coverage" (i.e. where understory growth covers a minimum distance inland of five meters) is used to calculate a ratio of intact understory coverage length / total site area length. Alternatively, the percent of the riparian area with intact understory vegetation per Quadrant can be estimated directly without a length measurement if desired. This percentage is used to determine the final metric score. Human influence is expected to reduce intact understory and increase degradation to the stream (Table 1).

SCORING - RIPARIAN UNDERSTORY COVERAGE

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Metric 10. Boulder / Cobble vs Soil Presence

Soil-derived material ($\leq$ 1 mm particle diameter) from the watershed, is deposited in streambeds as a result of watershed- and/or riparian-based disturbance to natural plant cover in the landscape which normally controls soil movement. High levels of soil presence / deposition in stream channels is symptomatic of chronic instability of stream banks, riparian over- and understory disturbance, and / or broad-scale landscape disturbance occurring in the watershed. Soil movement / deposition into the stream generally occurs during periods of heavy rainfall. This material is subsequently redistributed along the stream continuum depending upon flood duration and flow characteristics / patterns of the particular stream system. Long-term, chronically occurring soil deposition in stream channels eventually destroys natural physical stream habitat and functionality by burying rock substrate, smothering macroalgae and periphyton, and eliminating habitat / refugia for native aquatic species.

Reach quadrants are scored independently for this metric evaluating the extent to which optimal habitat exists. Percentage scores are averaged for the quadrants to determine total point scores. Key areas of focus for sediment deposition are runs / riffles particularly in areas of high sinuosity (i.e. meandering) where flow velocities are reduced.

Optimal	Suboptimal	Marginal	Poor
Boulder /Cobble substrate dominant feature of streambed; 0 % to 10 % of bottom affected by soil deposition.	Boulder / Cobble substrate common feature of streambed; 11% to 25 % of bottom affected by soil deposition.	Boulder/Cobble substrate marginal feature of streambed; 27 % to 50 % of bottom affected by soil deposition.	Boulder/Cobble substrate rare feature of streambed; greater than 51 % bottom affected by soil deposition.

SCORING – BOULDER / COBBLE VS. SOIL PRESENCE

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 Pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

THE HAWAII STREAM INDEX OF BIOTIC INTEGRITY (HS-IBI)

The HS-IBI is designed to classify or rate Hawaiian streams at various scales (i.e. reach to watershed) in terms of their biotic integrity as compared to that expected under reference stream conditions (Table 4). Each integrity class is characterized by expected attributes of the native macrofaunal stream assemblage at the individual, population, community, and ecosystem levels of organization (Table 4).

Table 4. HS-IBI ratings, integrity classes, and class attributes.

HS-IBI Score as % of Reference	Integrity Class	Attributes
90 - 100 %	Excellent	Comparable to reference conditions with minimal human disturbance; all expected native macrofauna present with alien *M.lar* either absent or in very low numbers; robust *'o'opu* populations meeting density and size-class expectations including those for sensitive *'o'opu* species (i.e. *'o'opu-nopili* and/or *'o'opu-alamo'o*); no disease or parasites observed on *'o'opu* species.
79 - 89 %	Good	All expected native macrofauna present; Alien *M. lar* present but in low proportionate abundance (< 10 %) compared to natives; total expected *'o'opu* populaion densites generally attained but sensitive *o'opu* densities and/or size classes may be somewhat below expectations; < 1 % of 'o'opu individuals with external symptoms of disease but no incidence of external leeches.
69 - 78 %	Fair	Most expected native macrofaunal species present; Alien *M. lar* present in substantial proportionate abundance (> 10 %) compared to natives; total *'o'opu* population and sensitive species densities / size classes below expectations; < 2 % of *o'opu* individuals with external symptoms of disease but no incidence of extemal leeches.
59 - 68 %	Poor	Few expected native macrofaunal species present; Alien *M. lar* as or more abundant than native species but other alien species absent or rare; total *'o'opu* population and sensitive species densities / size classes well below expectations; < 10 % of *'o'opu* individuals with external symptoms of disease but no incidence of external leeches.
40 - 58 %	Very Poor	Only one or two expected native macrofaunal species present and if present in very low abundance; Alien aquatic species dominate the community and may include tolerant fish species (e.g. Poeciliidae); between 2 % - 10 % of *'o'opu* individuals with external symptoms of disease and / or incidence of external leeches.
< 39 %	Impaired	Native aquatic macrofaunal species absent; Only alien species present including *M. lar* and tolerant fish species; > 11 % of *'o'opu* individuals with external symptoms of disease and / or attached leeches.

Native Macrofaunal Metrics

The biotic integrity metrics rely predominantly on the presence of the native Hawaiian macrofaunal stream assemblage which consists of five gobioid fish, two neritid mollusks, and two decapod crustaceans (Kinzie 1990) (Table 5). In addition, two generalized groups of alien aquatic species are utilized as indicators of human-induced degradation. Later versions of the HS-IBI may incorporate metrics for indicator algae and other invertebrate taxa to assess

instream primary / secondary productivity levels. The use of habitat metrics follow U.S. EPA guidelines (e.g. Barbour et al. 1997) but have been tailored to Hawaiian stream conditions. HSBP metrics incorporate "best available" ecological information on the native stream biota and have been crafted to measure biotic integrity and stream habitat quality as compared to that expected under reference conditions. The rational and ecological basis for the use of the various metrics will be discussed as each is explained.

Ten metrics are used in HS-IBI to provide ecological insight from the individual, population, and community levels of ecological organization. The HS-IBI value is obtained by summing the scores of the individual metrics to provide an overall means of rating sub-units of streams for

Table 5. Native Hawaiian stream macrofaunal assemblage.

Taxa	Hawaiian Name	Status
Teleostei; Perciformes; Gobioidei		
Eleotridae - *Eleotris sandwicensis*	*'o'opu-akupa*	endemic
Gobiidae - *Awaous guamensis*	*'o'opu-nakea*	indigenous
Lentipes concolor	*'o'opu-alamo'o*	endemic
Sicyopterous stimpsoni	*'o'opu-nopili*	endemic
Stenogobius hawaiiensis	*'o'opu-naniha*	endemic
Kuhliidae – *Kuhlia sandvicensis*	*aholehole*	endemic
Arthropoda; Crustacea; Decapoda;		
Atyidae - *Atyoida bisulcata*	*'opae-kala'ole*	endemic
Palaemonidae - *Macrobrachium grandimanus*	*'opae-oeha'a*	endemic
Mollusca; Gastropoda; Neritidae		
Neritina granosa	*hihiwai*	endemic
Theodoxus vespertinus	*hapawai*	endemic
Theodoxus cariosus	*hapawai*	endemic

Table 6. Biotic metrics and scoring used in the Hawaiian stream bioassessment.

METRIC	SCORING CRITERIA		
	pts 5	3	1
1a. Number of native amphidromous macrofauna (S_{NAM}) - High/Moderate Slope Mid Reach	4 - 3	2 - 1	0
1b. Number of native amphidromous macrofauna (S_{NAM}) - Low Slope Terminal Reach	6 - 5	4 - 2	1 - 0
2. Percent Contribution Native Taxa (PNT)	100% - 75%	74% - 50 %	$\geq$ 49 %
3. Percent Sensitive Native Fish (SNF)[1]	$\leq$ 50%	49% - 20 %	$\geq$ 19 %
4. Sensitive Native Fish Density (fish sq m^{-1})[2]	$\leq$ 0.46	0.45 - 0.20	$\geq$ 0.19
5. Sensitive Native Fish Size (% $\geq$ 6.0 cm)[3]	$\leq$ 50%	49% - 25 %	$\geq$ 24 %
6. *Awaous guamensis* Size (% $\geq$ 8.0 cm)[3]	$\leq$ 50%	49% - 25 %	$\geq$ 24 %
7. Total Native Fish Density (fish sq m^{-1})	$\leq$ 0.75	0.74 - 0.36	$\geq$ 0.35
8. Community Weighted Average (CWA)	1.0 - 4.0	4.1 - 9.0	9.1 - 10
9. Number of Alien Taxa (NAT)	0 - 1	2 - 3	>3
10. Percent Tolerant Alien Fish	0%	1 - 4%	$\geq$ 5%
11. Percent Diseased / Parasitized Fish	$\geq$ 1 %	2 % - 10 %	$\leq$ 11 %
Maximum Possible Points = 55			

[1] Sensitive species are *'o'opu-alamo'o* and *'o'opi- nopili*; total no. individuals / total no. fish only

[2] Either *'o'opu-alamo'o* or *'o'opu-nopili* (whichever is in highest density) but not both.

3 Excluding post-larval size-classes (≤ 3.0 cm TL).

biological quality (Table 4). The framework for scoring metrics as a "unit-less", semi-quantitative, numerical description of biological integrity on a scale that is relative to reference conditions follows EPA guidance (e.g. Barbour and Karr 1996; Karr and Chu 1997) (Table 6). Native aquatic macrofaunal species are used as biological indicators of stream quality as they are taxonomically unique, readily identifiable, specifically adapted to Hawaiian stream environments, known to be sensitive to environmental degradation, and found on all islands due to amphidromous life histories (Table 5). Of these native macrofauna, fish were used to specifically assess trophic and functional processes because of documented support for their use in the literature (e.g. Barbour and Karr 1996) and because most of the existing published ecological information for the native Hawaiian aquatic macrofauna pertains to fish (e.g. Ha and Kinzie 1997, Way et al. 1988, Kido 1996b). Specific details on the rationale, application, and expected responses of the ten macrofaunal metrics (Table 6) are discussed individually.

Metric 1. Number of Native Amphidromous Macrofauna (S_{NAM})
This metric assesses "species richness" in its simplest form (Ludwig and Reynolds 1988) as direct counts of the numbers of native aquatic species found in a particular study site. Scoring is scaled so as to partition variation in species numbers expected as a result of location along the stream continuum (Table 6, no.1a./1b.). Terminal reaches near the ocean are characterized by low slope gradients (< 4 %) and are expected to have greater species richness due to the presence of *Eleotris sandwicensis* ('*o'opu-akupa*), *Stenogobius hawaiiensis* ('*o'opu-naniha*), *Kuhlia sandvicensis* (*aholehole*) *Theodoxus vespertinus* (*hapawai*) and / or *Theodoxus cariosus* (*hapawai*) which prefer estuarine habitat and are not known to range into mountainous reaches (Kinzie 1990). In reference streams all expected native macrofaunal species are present. The numbers of native amphidromous species are expected to decline as environmental degradation increases through human influence.

Metric 2. Percent Contribution Native Taxa (PNT)
In its calculation, this metric is equivalent to Simpson's Diversity Index (Ludwig and Reynolds 1988) and is therefore a form of species richness measure.

$$PNT = \text{number native individuals / total number of individuals sampled}$$

In the HSBI this metric is primarily used to evaluate the proportionate abundance of native aquatic species relative to alien species in the sample population (Table 6, no.2). Under reference stream conditions, native aquatic species are numerically dominant (>75 %) and except for the amphidromous alien prawn *Macrobrachium lar*, alien species are entirely absent. Environmental degradation is expected to result in numerical declines in native aquatic species presence, proportionate increases in alien species presence, and resultant decline in PNT values.

Metric 3. Percent Sensitive Native Fish (SNF)

The proportionate abundance of *Lentipes concolor* (*'o'opu-alamo'o*) and / or *Sicyopterus stimpsoni* (*'o'opu-nopili*) in the sample population is used in this metric because of their trophic and environmental sensitivity.

SNF = number sensitive native fish species / total number of fish in the sample population

The two fish species are morphologically similar, reliant on benthic algae, and typically partition habitat so that they tend not to be syntopic (Kido 1996b). If the two species co-occur one tends to be present in significantly higher densities (Kido 1999). Both species are highly sensitive to environmental degradation and thus are reliable indicator species for assessments of stream biotic integrity. Under reference conditions, at least 50 % of the sample population of fish is expected to include one or both of these sensitive native species (Table 6, no.3).

Metric 4. Sensitive Native Fish Density

High proportionate abundance of sensitive *'o'opu* species may not necessarily coincide with the high absolute densities that characterizes robust fish populations in reference Hawaiian streams. In these streams sensitive *'o'opu* species are numerically dominant and consistently exceed (by several times) the conservative 0.46 fish per sq m standard established in the HS-IBI (Table 6, no. 4). This metric therefore supports Metric 3 by checking absolute densities of *Lentipes concolor* or *Sicyopterus stimpsoni* depending upon which is the dominant resident species. Sensitive fish densities are expected to decline with increasing human-induced degradation.

Metric 5. Sensitive Native Fish Size

The total length of *Lentipes concolor* or *Sicyopterus stimpsoni* individuals in the sample population is used in this metric as an overall indicator of community health. Size is a relatively easy attribute to measure in individual fish and is influenced by both environmental (e.g. food availability / quality, pollution, stressors, etc.) as well as population / community factors (e.g. predation, competition, disease, etc.). These two species can attain total lengths in excess of 10 cm in high quality Hawaiian streams (Kido 1999). Size is correlated with reproductive potential and this metric is thus also a useful indicator of the reproductive viability of the sensitive *'o'opu* community. Reproductive studies on *Lentipes concolor* by Way et al. (1998) suggest that females are reproductively active between 3.1 and 7.1 cm standard length. Based on these findings and preliminary reproductive data for *Sicyopterus stimpsoni* (M.H.K. unpublished), a total length of 6.0 cm is used as an expected value for 50 % of the sampled fish population as an indicator of robust biotic integrity (Table 6, no. 5). Fish populations in reference streams always meet or exceed this criteria indicating robust populations in terms of reproductive potential, trophic dynamics, species interactions, and environmental support. In order to eliminate the confounding effects of periodically high numbers of larval recruits in the population, counts of individual fish $\leq$ 3 cm are excluded from the calculation (Table 6, no. 5). The percentage of reproductively mature individuals in the population is expected to decline with increasing environmental degradation.

Metric 6. *Awaous guamensis (‘o’opu-nakea)* **Size**

Awaous guamensis is more widely distributed within- / between-stream systems and is also generally believed to be more tolerant to environmental degradation than either *Lentipes concolor* or *Sicyopterus stimpsoni*. *Awaous guamensis* is found syntopically with these latter two species in high quality streams but is typically found alone in streams of lesser environmental quality (M.H.K unpublished data). The rationale for use of this metric is the same as that for Metric 5 but focuses on a native species which may often be the only one present in a particular reach, segment or channel unit. This generalist species is known to rely on algae as well as invertebrates for food (Kido 1993) and is thus also a useful indicator of the general availability of foods in the benthos. Ha and Kinzie (1996) found that female *Awaous guamensis* were reproductively mature at a standard length of 7.3 cm and individuals can attain lengths of over 30 cm in reference streams (Kido 1999). A total length of 8.0 cm is used as an expected value for 50 % of the sampled fish as an indicator of a robust population and high stream biotic integrity (Table 6, no. 6). *Awaous guamensis* populations in reference streams always meet or exceed the expected value. As in Metric 5, counts of post-larval fish $\leq$ 3 cm are excluded from the calculation. Human-induced environmental degradation is expected to correlate with a greater proportion of smaller fish, reduced viability of the population, and compromised stream biotic integrity.

Metric 7. Total Native Fish Density

This metric uses the total density of native fish as an indicator of stream biotic integrity and supports Metric 4 (Sensitive Native Fish Density). Higher total fish densities correlate with more natural ecological functioning, higher environmental quality, lower numbers of alien species, and reduced human influence. Long-term monitoring data obtained for native fish populations in Limahuli Stream (Kauai) (Kido 1999) and comparisons with data from other high quality streams indicate that densities fluctuate around a mean value of 1.0 fish sq m^{-1} seasonally (Kido 1999). A more conservative value of 0.75 fish sq m^{-1} (or greater) is used in this metric as an expectation of high biotic integrity (Table 6, no.7). This is a conservative criteria as native fish densities in reference Hawaiian streams consistently exceed this expected value by a factor of two or three. Total native fish densities are expected to decline with increasing human-induced degradation.

Metric 8. Community Weighted Average (CWA)

The CWA is a numerical expression that reflects the relative sensitivity of various taxa to water quality / habitat degradation and the relative numbers of individuals in each taxon in a sample (Hilsenhoff 1987). This metric essentially scores the species diversity (by expected proportionate abundance) found in a stream site for its overall sensitivity to environmental degradation. Relative species rankings (weighting values) were derived through professional judgment and available ecological information.

The metric is calculated as:

$$\text{CWA} = \sum n^1 a^i / N = \text{species relative abundance x } a^i$$

where n^1 is the number of individuals in the ith taxon and a^i is the weighting value for that taxon, N is the total number of individuals in the sample. In reference streams native species dominate the community and aliens species are either absent or in very low proportionate abundance. The CWA value in a reference stream, therefore, never exceeds the 4.0 reference value (Table 6); however it is highly sensitive to increases in the proportionate abundances of tolerant and / or alien species. Human-induced degradation to the stream environment results in a decrease in sensitive native species abundance and an increase in tolerant and / or alien species abundance in the sample population that is reflected in a higher CWA value.

Table 7. Species weighting values for calculation of the CWA.

Weighting Values for Hawaiian Stream Macrofauna	
Species	**Weighting Value**
Lentipes concolor	1
Sicyopterus stimpsoni	1
Neritina granosa	2
Atyoida bisulcata	3
Macrobrachium grandimanus	3
Stenogobius hawaiiensis	3
Awaous guamensis	4
Eleotris sandwicensis	4
Alien Species - Group I[1]	**10**
Alien Species - Group II[2]	**9**

[1] **alien predators / competitors or disease vectors (e.g. Tilapia spp., Poeciliidae, etc.)**

[2] *Macrobrachium lar*

Metric 9. Number of Alien Taxa (NAT)
Reference Hawaiian streams either lack alien macrofaunal aquatic species entirely or have only one species present (i.e. the Tahitian prawn, *Macrobrachium lar*). Timbol and Maciolek (1978) identified a second alien crustacean (*Procambarus clarkii*) as well as fifteen alien fish species that were identified in Hawaii's one and only statewide survey of streams. Numbers of alien taxa were generally correlated with decreasing habitat quality and increasing human influence. Some of these alien species may not necessarily be numerically abundant and their importance, therefore, may be under-represented by Metric 2 (Percent Contribution of Native Taxa). Alien taxa presence, however, is a strong indicator of compromised stream biotic integrity thus the NAT metric is used to support Metric 2. Reference streams either have no alien species present or low numbers of *M. lar*. Human induced environmental degradation increases the numbers of alien species and is reflected in a decrease in the NAT score (Table 6, no.9).

Metric 10. Percent Tolerant Alien Fish
Of the fifteen alien fish species found in Hawaiian streams by Timbol and Maciolek (1978), poecillids (Poeciliidae) and tilapia (*Tilapia melanotheron*) were found to be the most widespread and troublesome. The rate of alien aquatic species introductions, however, have

increased dramatically in recent years with at least fourteen additional fish species recorded (Devick 1991). Tilapia have become very abundant in various streams, particularly on the island of Oahu (Devick 1991). Tilapia presence is detrimental to native fishes because of direct predation and increased competition for resources like food and space. Font and Tate (1994) have shown that poeciliid fishes are hosts for pathogenic parasites (leeches, tapeworms, and roundworms) that are transferred to native gobiioids. Swordtails (*Xiphophorous helleri*) can tolerate moderate stream flow conditions and thus range considerable distances into mountainous stream reaches where they can numerically dominate the fish population (M.H.K. unpublished). These alien fishes are highly tolerant of degraded conditions; therefore, their high proportionate abundance in the fish population is indicative of high levels of human-induced degradation. Reference streams do not have these alien fishes and the value of this metric will thus decrease as alien fish proportionate abundance increases (Table 6, no.10).

Metric 11. Percent Diseased / Parasitized Fish
This metric evaluates stream biological condition at the level of the individual by examining the proportion of fish sampled for external evidence of disease. Impaired environments are correlated with high incidence of disease / deformities in fish (e.g. Karr 1981) and benthic invertebrates (e.g. Hamilton and Saether 1971). As Hawaiian stream quality degrades, disease manifests most obviously in the increased occurrence of body lesions and the external alien leech, *Myzobdella lugribis* (Font and Tate 1994), in the population of native fishes. Disease occurrence is rare and parasite infestations are entirely absent in sampled native fish populations of reference streams but increases, first in the incidence of disease in the *o'opu* population and then in the proportion of individuals with attached alien leeches, as human influence escalates and stream quality degrades. In extremely degraded streams alien fish species will dominate the fish population and are also susceptible to disease and parasites; therefore, this metric will also be scored if only alien fish species are collected. Fish are sampled either through direct observation during UVC procedures or collected through electrofishing and physically examined by hand. A tally of the number of diseased individuals is kept on the UVC datasheet during the sampling procedure and used to calculate the per cent of the total number of fish observed or captured with disease symptoms and / or external parasites. The incidence of disease and parasitization is expected to increase as habitat quality degrades with increased human influence (Table 6, no. 11).

ASSESSMENT METHODS AND SAMPLING PROTOCOL

The sampling protocol is optimally executed by three trained personnel who should be able to complete the assessment procedures in a "normal" study site within three hours. A minimum two-person team is required for practical and safety purposes. The protocol has been designed to minimize observer bias and maximize between-observer repeatability. The use of a quadrant-based framework to divide the study reach into a manageable and easily observable system of discrete channel units is intended to provide a practical way of standardizing extremely heterogenous stream environments. The habitat and biotic assessment procedures are integrated in the protocol in a logical fashion that may be altered depending upon the situation presented at the time of sampling (e.g. number available personnel, size of stream, nature of terrain, etc.).

General Protocol Application

  I. Phase I - Delineates the "reach quadrant" system and initiates the habitat assessment:
    A. determine the total length of the study site;
    B. measure incremental slope and sinuosity (meandering) (optional);
    C. delineate the study site into measured "reach quadrants" through flagging;
    D. score the habitat types (Habitat Metric 1);
    E. locate and prepare channel units for UVC (underwater visual census) procedures.

  II. Phase II - Perform of UVC of macrofaunal population:
    A. assess fish and invertebrate population characteristics (HS-IBI Metrics 1 - 10), embededdness, CPOM / FPOM if UVC is used (Metrics 2 and 3);
    B. score channel status (Metric 5);
    C. score channel alteration (Metric 6);
    D. score bank stability (Metric 7);
    E. score riparian vegetation zone width (Metric 8);
    F. score percent riparian understory coverage (Metric 9);
    G. score boulder / cobble vs. soil presence (Metric 10);
    H. score FPOM / CPOM characterization (Metric 3) (if not done in UVC);
    I. score Embeddedness (Metric 2) (if not done in UVC);
    J. score depth and velocity attributes (Metric 4)

  III. Phase III - Perform additional tasks (optional)
    A. Take discharge measurements
    B. Measure stream riparian canopy coverage
    C. Photograph the site
    D. Collect specimens

Details on Specific Procedures

  Site Selection - Record all Data on Habitat Assessment Datasheet
      a. Determine study site length by taking four width measurements (bank to bank) at widest, narrowest, and at two intermediate points. Site length will be 20 times mean width. For streams < 5 m mean width, use a standard study site length of 100 meters.

b. To determine location to begin, look for repeating channel units (ie. runs, riffles, pools) separated by transition zones (step pools, chutes, cascades, or falls). Establish zero (i.e. first flag) just upstream of the transition zone start. Optimal sites will cycle through at least four channel unit sequences and begin just upstream of a transition zone.

c. Sites should be flagged at lengths that approximate 0 - 25 %, 25 - 50 %, 50 - 75 %, and 75 - 100 % distances of the study site. These will be designated QI, QII, QIII, and QIV respectively and separate the reach into four easily observable "reach quadrants" that have been individually measured using a tape or electronic measuring instrument. If desired, slope to each quadrant break is measured at this time using a clinometer and meandering (sinuosity) is recorded using a compass (degree change from initial direction). These data are useful in performing between-site comparisons but not used directly in the habitat assessment and thus are optional. In reaches of streams with very high slope variance, it may be necessary to take readings at shorter interval.

d. In the absence of clinometer measurements, channel gradient (slope = elevation rise / total reach length) can be determined visually by roughly estimating the average height of cascades in the study reach. "High Gradient" reaches (> 10 % slope) are characterized by the presence of cascades or falls > 2 m high. Cascades between 0.5 m to 2 m high are characteristic features of "Medium Gradient" reaches (5 % to 9 % slope). In "Low Gradient" reaches cascades are rare and if present are < 0.5 m high. Total slope for the study reach can also be roughly measured by taking an altimeter reading at the 0 % and 100 % locations in the study reach.

HABITAT ASSESSMENT PROCEDURES
Metric 1. Determination of Habitat Types

Beginning at the 0 % flag position, the stream channel is traversed in an upstream direction and the available habitat types observed are scored for each quadrant (i.e. QI to QIV) as described for Metric 1 (Pg. 8; Table 2a, 2b). A running tally is kept of the number of habitat types occur. Each quadrant is expected to have all habitat types expected for each respective slope gradient range and the final percentage is calculated based on the total observed / total expected habitat types. Observed habitat types are checked-off the list on the habitat assessment datasheet for each Quadrant (Fig. 3a).

Metric 2. Embededdness

This metric (as well as FPOM / CPOM and Boulder / cobble vs. Soil) is easier to score in highly degraded streams where the channels are highly sedimented but more difficult where conditions are less extreme. If UVC cannot be used in the study site, select at least two riffle / run / shallow pool habitat in each reach quadrant for sampling as these will be deposition zones where smaller particles will settle. Using the criteria, score each habitat (Optimal to Poor or by percentage) overall for the degree to which cobble / boulder is buried by gravel-sized and smaller particles. If UVC can be used, divers evaluate substrate embededness during their dive in the sq m observation cells. Details for alternative methods to locate observation cells are given in the UVC section (p. 29) but the "Line Method" is recommended. After fish are counted / measured in

observation cells (sq m quadrat) during the UVC, the quality of the substrate habitat in each observation cell along the line transect is evaluated for embededdness based upon the criteria. This rating (i.e. Optimal, Suboptimal, Marginal, Poor) is recorded on the visual census datasheet in each individual observation cell.

Metric 3. FPOM / CPOM Characterization
After embededdness is scored (Metric 2), FPOM / CPOM coverage is evaluated according to the criteria described for Metric 3 (Pg. 10) in the identical observation area (without UVC) or square meter observation cells (with UVC) used for scoring embededdness. It is easiest if the two metrics are scored consecutively and the FPOM / CPOM condition for the observation cell (i.e. Optimal, Suboptimal, Mariginal, or Poor) or observation area. Data is recorded on the visual census datasheet with UVC or the Habitat Datasheet without UVC.

Metric 4. Velocity-Depth Combinations
Each of the four reach quadrants are scored for available velocity depth combinations using the depth / flow criteria described in Metric 4 (Pg. 10) and listed on the habitat datasheet (Fig. 3b). This evaluation should be done after underwater visual census procedures are completed so as to minimize disturbance to fish and invertebrate populations. If possible, a wading rod and flow meter should be used to verify actual depths and mean flow velocities encountered (especially for the fastest flows). Experience will permit users to score by observation once the highest observed velocities are measured.

Metric 5. Channel Flow Status
This metric is meant to evaluate the degree to which water if filling the channel from bank-to bank and from top-to-bottom and can be scored anywhere along the study reach where natural banks and a typical U-shaped stream channel can be located (Fig. 2). Observations should also be made as to the extent of cobble / boulder exposure, swiftness of flow, evidences of high water marks, etc. to provide corroboration. Under natural low-flow or severely dewatered conditions ("Poor" Rating), the stream may be totally dry or just a ribbon standing or barely flowing in the very lowest portion of the channel. Under "Marginal" conditions, water is actually touching both banks but filling from 26 % to 50 % of the channel as evidenced by excessive exposure of cobbles / boulders situated in the streambed (Fig. 2). As channel flow status improves (Good Rating) depth of water filling the channel increases (51 % to 75 %) with higher flow velocities and less exposed cobble / boulder in the study reach (Fig. 2). Under "Excellent" conditions, the stream channel is from 76 % to 100 % full with water close to or at the level of the banks (Fig. 2). Observation of an "Ordinary High Water Mark" (OHM), defined by indicators such as water marks on the bank (e.g. variation in color or a distinct line) and / or a distinct change in vegetation type along banks, may be useful in assessing the normal upper extent of stream flow in the channel.

Metric 6. Channel Alteration
This is a direct measurement of the total length of stream channel altered. Using a tape or electronic device, measure the straight line distance in the center of the stream bed of channelized, dredged, or otherwise altered segments in each of the reach quadrants as described

for Metric 6 (Pg. 13). These channel lengths are recorded individually on the habitat assessment datasheet (Fig. 3a) and used with the total measured study site length to calculate the percent of channel altered. Alternatively, the estimated percentage of altered channel to total channel length may be determined through observation.

Metric 7. Bank Stability
Measure the straight line distance of eroded, muddied or otherwise disturbed areas of each bank separately and record these values on the habitat assessment datasheet for each bank (Fig 3b). The sum of these lengths are divided by the total measured bank lengths of the study site to obtain a "percent of stable bank" value which is used for scoring the metric. Alternatively, the estimated percentage of disturbed to total bank length may be determined through observation.

Metric 8. Riparian Vegetative Zone Width
The objective in this metric is to determine the length of the riparian zone in which width is four times mean width of the study stream reach. Using the mean width measured and recorded initially, calculate the four times width value and estimate (or if necessary measure) its extent into the riparian zone on each bank individually. Subsequently determine the length of each bank's riparian zone for each reach quadrant that meets the designated width criteria (Pg. 14). This determination may be made by taking an actual length measurement using a tape or electronic measurer; however, in practicality an "eyeballed" estimate of the extent of % coverage of each quadrant will yield acceptable data. These values are recorded in the habitat assessment data sheet. If linear measurements are taken, use the percentage calculated by dividing total riparian lengths /
total bank length to score the metric. If percentages were estimated then use these directly to determine the score.

Metric 9. Percent Riparian Plant Understory Coverage
The observation point to score this metric is in the center of the stream channel so that both banks can be observed and scored consecutively in each reach quadrant. The objective is to determine the area covered by mature plant understory growth for right and left banks separately from the water's edge to a distance of five meters into the riparian zone. These data are recorded in the habitat assessment data sheet (Fig. 3b).

Metric 10. Boulder / Cobble vs. Soil Presence
The objective in scoring this metric is to determine the relative availability of natural boulder / cobble in the stream channel as well as the percent of area affected by sediment deposition. Reach quadrants are scored independently for this metric and scores are averaged in the summary sheet to determine total point scores. The metric may be scored at any point in the habitat assessment procedure; however, it is likely most effective to make a determination after scoring the habitat metrics (e.g. flow characteristics [Metric 4], habitat availability [Metric 1], and channel status [Metric 5]) as the observer would have had sufficient time to view a substantial portion of the stream channel to be scored. These data are recorded in the habitat assessment data sheet.

Figure 3a. HSBP Habitat Field Data Sheet (Version 3.01) - Page 1.

DATE:_____   STREAM:_____   SITE: _____

TIME st:_____ end:_____   DATA: HABITAT PG1   PERSONNEL_____

ELEVATION 0: _____ 100% _____ TOT SLOPE = _____
                    STREAM   STUDY REACH LENGTH _____
WIDTH   WIDE _____   MEAN WIDTH _____
             NARROW _____   20X MEAN W _____
             MEDIAN _____   _____
GPS N _____ W _____
   HABITAT TYPES SLOPE TYPE H>10% M5-9% L<4% _____
score number of habitat types

QUADRANT	I	II	III	IV
RUNS EB				
NOEB				
POOLS DAM				
SCOUR				
RIFFLES EB				
NOEB				
TRANS STEP				
CHUTES				
CASCADE				
FALLS				
TOTAL TYPE				
% HABITAT TYPES				

% REACH	DISTANCE	SLOPE	SINUOSITY
0% -			
25% -			
50% -			
75% -			

ALTERED CHANNEL (MEASURED LENGTH OR % OF REACH ALTERED)

QUADRANT	I	II	III	IV
LENGTH				

EMBEDEDDNESS (% OF AREA OPTIMAL= 0-10% BURIED BY SEDIMENT

QUADRANT	I	II	III	IV
LENGTH				

FPOM / CPOM (% OF AREA OPTIMAL= < 10 % COVERED)

QUADRANT	I	II	III	IV
LENGTH				

FINAL HSBP CHECKLIST ON BACK - CHECK OFF [HSPB Field Datasheet Version 3.01 (1/02)]

Figure 3b. HSBP Habitat Field Data Sheet (Version 3.01) Page 2.

DATE:_____   STREAM:_____   SITE: _____

TIME st:____ end:_____   DATA : HABITAT PG2   PERSONNEL:_____

VELOCITY-DEPTH COMBINATIONS – CHECK OFF IF PRESENT

QUADR V=msec^1 Depth m	I	II	III	IV
SL-DEEP <0.2 >0.71				
SL-SHAL <0.2 <0.25				
SL-INTER <0.2 0.26-0.70				
MOD-SHL 0.21-0.89 <0.25				
MOD-INTER 0.21-0.89 0.26-0.70				
FAST-SHL >0.9 <0.25				
FAST-INTER >0.9 0.26-0.70				

BANK STABILITY (MEASURED LENGTH OR % BANK ERODED OR DISTURBED)

QUADRANT	I	II	III	IV
R BANK				
L BANK				

RIPARIAN ZONE WIDTH (% OR LENGTH >4 TIMES MEAN STREAM WIDTH)

QUADRANT	I	II	III	IV
R BANK				
L BANK				

RIPARIAN UNDERSTORY (% OR LENGTH >4 TIMES MEAN STREAM WIDTH)

QUADRANT	I	II	III	IV
R BANK				
L BANK				

COBBLE/BOULDER VS. SOIL (PERCENT OF QUADRANT AREA OPTIMAL)

QUADRANT	I	II	III	IV
Optimal	**Suboptimal**	**Marginal**	**Poor**	
Boulder /Cobble dominant feature; 0% to 10 % of bottom affected by soil – 100% to 80%	Boulder / Cobble common feature; 11% to 25 % of bottom affected by soil – 79% to 51 %	Boulder/Cobble substrate marginal feature; 27 % to 50 % of bottom affected by soil – 50% to 26 %	Boulder/Cobble substrate rare feature; greater than 51 % bottom affected by soil Less than 25 %	

CHANNEL STATUS (% OF WATER-LEVEL FILLING CHANNEL)

QUADR	I	II	III	IV
Optimal	**Suboptimal**	**Marginal**	**Poor**	
Water flowing in the channel touching both banks filling from 76 %	Water flowing in the channel touching both banks filling from 51 %	Water visibly flowing in the channel; not touching banks filling	No visible flow (0) or a narrow ribbon of flow in channel	

Native Fish and Macroinvertebrate Assessment Procedures
Underwater Visual Census (UVC)
Underwater visual census (UVC) has become a standard method for estimating densities and relative abundances of native fish species in Hawaiian streams (Baker and Foster 1992; Kido et al. 1994). In stream channels where UVC can be safely and effectively used, divers will snorkel through the entire study reach scoring the total lengths of fish observed by species, total lengths of prawns species (eye-orbit to telson), maximum shell widths of molluscs species, and numbers (but not sizes) of atyid shrimp on waterproof datasheets (Fig. 4) that are secured by clips to underwater slates. Quantifying numbers and size-classes of stream species in this manner is referred to in the HSBP as a "linear count" since divers essentially follow a "linear" path upstream through the length of the study site. These data will provide the numbers and sizes of aquatic species required for scoring the S_{NAM}, PNT, SNF, CWA, and NAT metrics.

For metrics scoring fish densities, sites within each reach quadrant must be cautiously selected and the observer must exercise "experienced choice" in order to select appropriate channel units for sampling. Because reach quadrants have repeating channel unit types, habitats are generally sampled in proportion to their availability in the study site. Observation areas should provide optimal habitat for stream organisms (therefore exhibit maximum species densities) as well as optimize the observer's physical ability to survey the area. Recommended habitat for sampling, therefore, are runs and / or pools within channel units that have moderate depth (~0.5 m) and minimal coverages of exposed boulders. Riffles may be used if they are deep enough for divers to pass. Our stream monitoring studies have shown that the highest fish densities are generally found in these optimal habitat and fish density metrics have been structured around maximum species densities expected in these habitat. Avoid areas that have excessive exposed substrate as these habitat will introduce diver bias and errors in observation as well as increased difficulty in determining the size of the sampled area. At least two optimal habitats within each reach quadrant must be sampled.

Two methods the "Point Method" and "Line Method" are recommended for estimating fish densities using UVC and will yield similar fish density results if executed properly (Kido et al 1994). These data are used to score metrics for Sensitive Native Fish Density (HS-IBI Metric 4) and Total Native Fish Density (HS-IBI Metric 7). Both methods are based on a sampled area coverage of 20 % of available channel unit habitat using a standard one square meter observation cell. A pool 10 m x 10 m, therefore, will require that 20 sq m meters be randomly selected and surveyed (10 m^2 = 100 sq m; 20 % = 20 sq m). Regardless of the method chosen, the general idea is that every observation cell in the channel unit being sampled will have an equal chance of being selected. Random numbers needed to identify location can be simply determined in the field using dice or numbers scribbled on pieces of paper.

> The "Point Method" recommended is similar to Baker and Foster's (1992) but uses a standard quadrat size (observation cell) of one square meter and sets a minimum area coverage of 20 %. The cell is positioned in the stream through generation of a set of random numbers that locates an "up-stream" and "across-stream" point on the stream bottom. One of the difficulties of using this method is the need to pre-generate pairs of

random numbers which have to be arranged in ascending order so that the diver can hit each point moving in an upstream direction. It is also difficult for the diver to locate precisely the designated random point without placing an obvious marker on the stream bottom. Failure to locate this point precisely will lead to serious diver bias and error (Kido et al. 1994). Embeddedness and substrate metrics (Metric 1 and Metric 2 respectively) also will have to be scored concurrently with the species survey unless point locations are marked.

The "Line Method" (Kido et al. 1994) is simpler to use and differs from the "Point Method" in that only one randomly selected "up-stream" point has to be identified. At this location on the stream bank, a line flagged at square meter intervals is anchored from bank to bank. The line, therefore, clearly delineates a contiguous grid of square meter-sized observation cells across the stream that facilitates the fish observations and ensures that the entire stream cross-section is sampled. The line simplifies the scoring of embeddedness (Metric 1) and substrate characteristics (Metric 2) which can be scored using the lined-grid during or after the fish survey. In long-term monitoring studies, line anchor points on banks are flagged so that exact locations may be repeatedly surveyed. An added benefit of the method is that divers are able to remain in the water for the entire survey and do not have to exit to locate the next point location thereby minimizing disturbance.

Regardless of the UVC method chosen, total lengths of fish and prawns by species, shell diameters of snails, and numbers of atyid shrimp are recorded for each observation cell providing data on both species numbers, densities, and size class composition of the sampled population. Because the standard observation cell is one square meter, density values are recorded as individuals observed per square meter. This can present technical problems depending on the situation encountered during sampling. Divers must ensure that a full square meter area is scanned. If the cell selected is filled with substrate that eliminates or obscures habitat, then the "available" area must be measured and recorded or the cell not counted. For simplification, if greater than 50 % of the observation cell is unusable then do not score the cell. Densities observed in observation cells are averaged across all reach quadrants to give a mean species and total fish density for each reach quadrant as well as for the overall study site.

Figure 4. Underwater visual census datasheet.

DATE:_____   STREAM:_____   SITE: _____

TIME st:_____ end:_____   DATA:_____   PERSONNEL_____
                                                                    PAGE NO. _____

Electrofishing Alternative

In streams that are very shallow or polluted, UVC cannot be utilized and we suggest the use of electrofishing techniques as an alternative method for sampling the aquatic fauna. This was the primary collecting method used by Timbol and Maciolek (1978) for sampling Hawaiian streams and Karr (1981) demonstrated its effectiveness in sampling fish populations as indicators of stream biotic integrity. Electrofishing gear differ in catching capacities / voltage intensities, are ineffective in slow-moving water and must be used by adequately trained / equipped personnel. Biotic metrics in the HSPB that require only size measurements or rely on species relative abundance can be utilized as long as equal effort is used to capture organisms in each of the reach quadrants. Absolute estimates, however, are more problematic because insufficient testing has been focused on relating UVC data to electrofishing data. More than likely in stream sites where UVC cannot be used, very few (if any) native stream species will be present; therefore, all HS-IBI metrics can be scored. Scoring HS-IBI Metrics 4 and 5 are problematic if significant numbers of native species are captured since density or some "catch per unit effort" is required. If this occurs score these metrics as "three" to provide an intermediate value. This is an interim solution and further testing is needed to equate UVC data to data obtained through the use of electrofishing techniques.

ADDITIONAL FIELD DATA COLLECTION
Stream Flow Measurement

It is a good idea to take at least one flow measurement in the study site before leaving as it will provide a comparable measure of stream condition / size that will be useful in future analyses in particular comparisons with USGS flow gage records (when available). Flow meters are either electronic or mechanical and generally measure flow by counting the number of ions passing a sensor or the number of revolutions of a propeller over time at a series of depths across the channel. A top-setting wading rod is used to hold the sensor or propeller sensor at a height that is 60 % of depth measured at the particular location. This is defined as the "mean flow."

To determine "generalized mean flow" (or discharge), select a portion of the stream site in which a narrow and unobstructed channel is available with little or no exposed boulder. Look for a relatively uniform streambed comprised of either bedrock or uniform substrate particles. These conditions may not always be available so the "best available" habitat may have to be settled for. Secure a tape or transect line across the channel and measure depth / mean flow at pre-determined intervals across the stream channel using a flow meter and top-setting rod. Flow measurement can be very time consuming if highly accurate flow data is required and many individual measurements are taken; therefore, I recommend as a general rule-of-thumb, for streams with measured width of < 10 m, 4 m to 9 m, and 1 m to 3m, take depth / mean flow measurements at 1.0 m, 0.5 m, and 0.2 m – 0.25 m intervals respectively across the stream channel. These "generalized mean flow" data have their limitations and should be used for general comparisons only.

Incremental flows measured at each interval and depth are summed to determine "generalized mean flow", Q as:

$$Q = w^1 D^1 v^1 + w^2 D^2 v^2 + \ldots + w^n D^n v^n$$

where w is the interval width in meters, D is the interval midpoint depth in meters and v is the mean water velocity.

Estimating Riparian Canopy Coverage

Riparian zones dominated by aggressive alien tree species are typical along the continuum of most streams in Hawaii today. These trees not only deposit large quantities of organic matter onto riparian banks and into the stream, but cover the stream channel to varying degrees reducing or (in come cases) eliminating light penetration onto the stream's surface (Kido 1999). Light-limited Hawaiian streams have lowered primary production potential / algal biodiversity and resultant reductions in population densities of herbivorous native stream species such as the *'o'opu-nopili* (Kido 1999). Although not a formal component of the HSBP, routine collection of data on riparian species abundances / composition and the degree to which the canopy covers the stream provides useful insight into an important habitat attribute which can exert significant influence over stream ecological functional.

At two randomly chosen points in each of the four reach Quadrants a meter transect is secured across the stream channel and densiometer measurements are made from bank-to-bank. The densiometer allows the observer to observe a point directly overhead of the meter mark to determine if the stream channel is covered by riparian canopy. This is recorded on the canopy datasheet (Canopy Datasheet HSBP vers 3.01.doc) included on this CD-ROM along with an abbreviation for the particular tree species involved. Summing the total number of sq m cells with or without canopy cover divided by the total cells observed yields a % closed or % open riparian canopy value respectively. In similar fashion, the % abundance of each tree species involved in the riparian canopy over the stream can be calculated.

SUMMARIZING FIELD DATA
Data Analyses

After the field assessment is completed, raw field data from the habitat assessment datasheet are transcribed onto the Summary Worksheet printed from the Word file provided (HSBP Worksheet Vers. 3.01.doc). The Summary Worksheet (pages 35 - 39) will provide a back-up record of the field assessment data and be used to calculate, record and summarize scores for the individual habitat metrics. An Excel 2000 spreadsheet (HSIBI Raw Data Vers 3.01.xls) is also provided on the disk for recording UVC data and to simplify calculations needed to score the metrics for the HS-IBI (see notes below). The manual will be needed during this process for scoring metrics and determining final scores. Formulas in this spreadsheet can be copied into the appropriate cells to calculate the overall Habitat and HS-IBI rating (i.e. Excellent to Impaired). Final scores determined for the Habitat and HS-IBI metrics can be recorded in the summary table worksheet also provided on the disk (HSBP- Table 3.01.xls). This spreadsheet can be imported and converted directly by *ArcView* (ESRI, Inc.) into .shp files for use in the Geographical Information System (GIS).

Computer Files

Six computer files are included with the .pdf version of the HSBP manual on this CD-ROM to facilitate application of the HSBP in the field. Data sheets for the Under Water Visual Census (UVC) procedure (HSBP UVC Datasheet vers 3.01)(Fig. 4) and habitat assessment procedure (HSBP Field Datasheet Vers 3.01 Pg 1 and 2)(Fig. 3a, 3b) are provided as Word 2000 files and are intended to be printed using a laserjet printer. UVC and habitat field datasheets are designed to be printed onto both sides of letter-size waterproof paper (All-weather copier pak no. 8511, J.J. Darling Corporation) using an ordinary laserjet printer and cut in half to fit the standard slate. Inkjet printers cannot be used for this purpose as the ink will smear when exposed to water. The sheets will fit see-through acrylic underwater slates that use a standard size of 15 cm X 23 cm and have a metric ruler glued to its base. Inexpensive small binder clips provide an effective and inexpensive method of securing data sheets to slates during UVC execution.

Raw HS-IBI data from the UVC datasheet are entered into the starter Excel 2000 spreadsheet provided (HSIBI Raw Data Vers 3.01) using existing data as a template. Calculation of metric values is simplified by using the embedded formulas. Simply copy these formulas into the appropriate rows / columns of the newly entered dataset; however, be sure to re-enter the specific cell ranges each time as no two datasets will have the same number of observations. Also, always check that the summed species percent abundance total is 1.0 verifying that species numbers and size-classes were entered properly in the spreadsheet.

For summarizing raw HSBP field data, a worksheet in Word 2000 (HSBP Worksheet Vers 3.01) (Fig. 3) is also provided. Print hardcopies of the worksheet for use with the HSBP Manual to arrive at point scores for each of the habitat and biotic integrity metrics.
Final Habitat / HS-IBI metric values are entered into the HSBP Table Vers 3.0.xls which can be imported directly into the *ArcView* GIS (ESRI, Inc.) for display and mapping.

Figure 5. Worksheet for summarizing raw HSBP field data (HSBP Worksheet vers 3.01).

Summary Worksheet - Hawaii Stream Bioassessment Protocol
UH-HSRC Version 3.01 (1/02)   Habitat Score_____
HS-IBI Score_____

Date:_____ Island:_____ Stream:_____

Site Description :_____

GPS N_____ W _____ Site _____

Elevation 0 (m): _____ 100%:_____ TSlope:_____ Type:_____

Mean Stream Width + SE (m):_____ TReach Length:_____

TLength: QI_____ QII_____ QIII_____ QIV_____

TSlope: QI_____ QII_____ QIII_____ QIV_____

TSinuous: QI_____ QII_____ QIII _____ QIV_____

AvgSinuous+SE _____ AvgSlope+SE_____

Personnel:_____

Notes:

HABITAT ASSESSMENT
1. Habitat Availability

Reach Quadrant	I	II	III	IV	Total
No. Habitat Types					
Percent Possible Habitat					
Total % Habitat Type	Total Points				

Habitat Type	High Slope (> 10%)	Medium Slope (5% - 9%)	Low Slope (< 4%)
Runs			
Exposed Boulder (EB)	X	X	X
No Exposed Boulder (NoEB)	X	X	X
Pools			
Scour	X		
Dammed	X	X	X
Riffles			
Exposed Boulder (EB)	X	X	X
No Exposed Boulder (NoEB)	X	X	X
Transition Zones			
Steps	X		
Chute	X	X	
Cascade	X	X	X
Falls (> 3.0 m height)	X		
Expected Habitat Types	5 to 11	4 to 8	3 to 6

SCORING - PERCENT POSSIBLE HABITAT TYPES

Optimal					Suboptimal					Marginal					Poor				
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	5	<2
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

2. Embeddedness

Reach Quadrant	No. Optimal	No Sub Opt.	No. Marginal	No. Poor
Q I				
Q II				
Q III				
Q IV				
Total No.				

Total Optimal / Total SU =		Total Points =	

Optimal	Suboptimal	Marginal	Poor
Substrate 0 - 10 % surrounded by sediment	Substrate 11 - 25 % surrounded by sediment	Substrate 26 - 74 % surrounded by sediment	Substrate > 75 % surrounded by sediment

SCORING - EMBEDDEDNESS - PERCENT OPTIMAL-SUBOPTIMAL QUADRATS

Optimal					Suboptimal					Marginal					Poor				
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	5	<2
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1

3. FPOM / CPOM Characterization

Reach Quadrant	No. Optimal	No Sub Opt.	No. Marginal	No. Poor
Q I				
Q II				
Q III				
Q IV				
Total No.				

Total Optimal / Total SU =		Total Points =	

Optimal	Suboptimal	Marginal	Poor
FPOM / CPOM localized covering < 10 % of sq m quadrat;	FPOM / CPOM uncommon covering 11 - 25 % of sq m quadrat;	FPOM / CPOM widespread covering 26 - 50 % of sq m quadrat;	FPOM / CPOM dominant covering >51 % of sq m quadrat;

SCORING - SUBSTRATE CHARACTER - PERCENT OPTIMAL-SUBOPTIMAL QUADRATS

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

4. Velocity-Depth Combinations

Reach Quadrant	I	II	III	IV	Tot Poss
No. Velocity Depth Regimes					
% Possible Regimes					

Total % V-D Regimes =		Total Points=	

Flow Regime	Depth (meters)	Velocity (meters per sec)
slow flow-deep	> 0.71	< 0.20
slow-flow shallow	< 0.25	< 0.20
slow flow- intermediate depth	0.26 - 0.70	< 0.20
moderate flow- shallow	< 0.25	0.21 - 0.89
moderate flow- intermediate depth	0.26 - 0.70	0.21 - 0.89
fast flow- shallow	< 0.25	> 0.90
fast flow- intermediate depth	0.26 - 0.70	> 0.90
High-Medium Slope (5 to 30 %) – Six Flow Regimes Expected Per Quadrant		
Low Slope (< 4 %) – Four Flow Regimes Expected Per Quadrant		

Points for velocity-depth combinations in total study reach (ie. all reach quadrants)

Optimal				Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

5. Channel Flow Status

Optimal	Suboptimal	Marginal	Poor
Water flowing in the channel touching both banks filling from 76 % to 100 % of cross-section.	Water flowing in the channel touching both banks filling from 51 % to 75 % of cross-section.	Water visibly flowing in the channel filling from 26 % to 50 % of the channel cross-section	No visible flow (0) or a narrow ribbon of flow in channel cross-section (25%)

SCORING - PERCENT OPTIMAL CHANNEL STATUS CROSS-SECTIONS

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Reach Quadrant	I=	%	II=	%	III=	%	IV=	%
Stream/Channel Ratio	Avg % =				Total Points =			

6. Channel Alteration

Reach Quadrant	I	II	III	IV	Total
Length Altered Channel m					
% Altered Channel =		Total Points =			

SCORING - PERCENT ALTERED CHANNEL

Optimal					Suboptimal					Marginal					Poor					
0%	2	4	6	8	10	13	16	19	21	24	29	34	39	44	49	59	69	79	89	100
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

7. Bank Stability

Reach Quadrant	I	II	III	IV	Total
Right bank eroded L(m)					
Left bank eroded L(m)					
Total eroded quadrant L(m)					
% Eroded Bank =		Total Points =			

SCORING - PERCENT UNSTABLE BANK

Optimal					Suboptimal					Marginal					Poor					
Bank 0%	2	4	6	8	10	13	16	19	21	24	29	34	39	44	49	59	69	79	89	100
pts 20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

8. Riparian Vegetative Zone Width (4X Mean Stream Width)

Reach Quadrant	I	II	III	IV	Total
Right bank Riparian L(m)					
Left bank Riparian L(m)					
Total Riparian L(m)					
Total % Riparian =		Total Points =			

SCORING - RIPARIAN ZONE WIDTH

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

9. Percent Riparian Mature Understory Coverage

Reach Quadrant	I	II	III	IV	Total
Right bank understory					
Left bank understory					
Total Riparian Area					
Total % understory =		Total Points =			

SCORING - RIPARIAN UNDERSTORY COVERAGE

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	5	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

10. Cobble / Boulder vs. Soil Presence

Reach Quadrant	I	II	III	IV	Total
% of habitat in Optimal status					
Average % Deposition =		Total Points =			

Optimal	Suboptimal	Marginal	Poor
Boulder /Cobble substrate dominant feature of streambed; 0 % to 10 % of bottom affected by fine sediment deposition.	Boulder / Cobble substrate common feature of streambed; 11% to 25 % of bottom affected be fine sediment deposition.	Boulder/Cobble substrate marginal feature of streambed; 27 % to 50 % of bottom affected by fine sediment deposition.	Boulder/Cobble substrate rare feature of streambed; greater than 51 % bottom affected by fine sediment.

SCORING – Sediment Deposition

Optimal					Suboptimal					Marginal					Poor					
100%	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	0
20 pts	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

Reach Quadrant	I=	%	II=	%	III=	%	IV=	%
	Avg % =				Total Points =			

HABITAT ASSESSMENT – SUMMARY TABLE

Metric	Total Score	Total Points
1. Habitat Availability		
2. Embeddedness		
3. FPOM / CPOM Characterization		
4. Velocity-Depth Combinations		
5. Channel Status		
6. Channel Alteration		
7. Bank Stability		
8. Riparian Zone Width		
9. Riparian Understory		
10. Cobble/ Boulder vs. Soil Presence		
Totals		
% of Possible		

HS-IBI
Native Fish and Macroinvertebrate Metrics

METRIC	Value	Points
1a. Number of native amphidromous macrofauna (S_{NAM}) - High/Moderate Slope Mid Reach		
1b. Number of native amphidromous macrofauna (S_{NAM}) - Low Slope Terminal Reach		
2. % Contribution Native Macrofauna Taxa (PNT)		
3. % Sensitive Native Fish Species (SNF)[1]		
4. Sensitive Native Fish Density (fish sq m^{-1})[2]		
5. % Sensitive Native Fish Size (% $\leq$ 6.0 cm)[3]		
6. % *Awaous guamensis* Size (% $\leq$ 8.0 cm)[3]		
7. Total Native Fish Density (fish sq m^{-1})		
8. Community Weighted Average (CWA)		
9. Number of Alien Taxa (NAT)		
10. Percent Tolerant Alien Fish Species		
11.Percent Diseased / Parasitized Fish		
Totals		
% of possible		

[1] Sensitive species are *'o'opu-alamo'o / nopili*; use both species ratio to total fish only

[2] Either *'o'opu-alamo'o* or *'o'opu-nopili* (whichever in highest density) but not both.

[3] Excluding post-larval and immature classes (< 4.0 cm TL).

Calculation of Community Weighted Average (CWA)

$$CWA = \sum n^1 a^i / N = \text{species relative abundance x } a^i$$

.

Weighting Values for Hawaiian Stream Macrofauna	
Species	**Weighting Value**
Lentipes concolor	1
Sicyopterus stimpsoni	1
Neritina granosa	2
Atyoida bisulcata	3
Macrobrachium grandimanus	3
Stenogobius hawaiiensis	3
Awaous guamensis	4
Eleotris sandwicensis	4
Alien Species - Group I[1]	10
Alien Species - Group II[2]	9

[1] alien predators / competitors or disease vectors (e.g. Tilapia spp., Poeciliidae, etc.)

[2] *Macrobrachium lar*

APPLICATIONS OF THE HSBP

The HSBP is intended to provide a standardized protocol for assessing stream habitat and biotic quality in the State of Hawaii. There are multiple ways in which the protocol can be applied and the data utilized depending upon the questions posed. The focus on assessment at the channel unit scale was intended to provide higher resolution for identifying sources of degradation and affected ecological components. Close
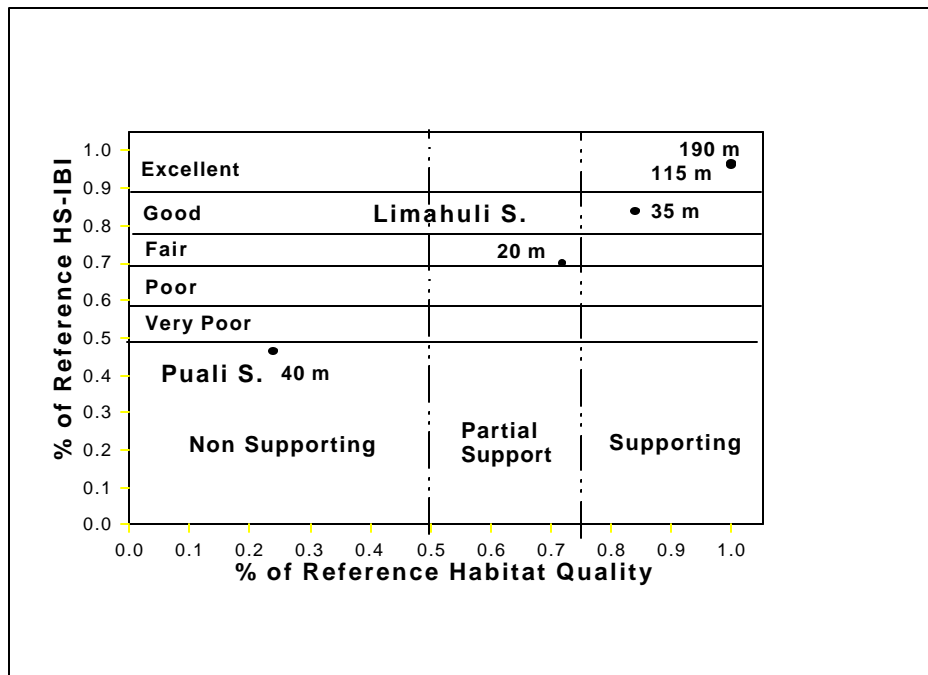

Figure 6. Stream biotic integrity vs habitat quality for Puali and Limahuli Streams, Kauai.

scrutiny of the data will reveal the nature of the degradation and to a limited degree the specific ecological processes (e.g. food availability, nutrient inputs, etc.) that are being impacted. Absence or low densities of *Sicyopterus stimpsoni* (*'o'o'pu-nopili*) in the fish assemblage, for example, suggests that the quality of the benthic algal food base, upon which this species is reliant (Kido 1996a), has been somehow degraded. Future incorporation of algal and invertebrate metrics into the HSBP, however, is needed to provide more specific information about the nature of the impact and how trophic processes are being affected.

Site Assessment

Perhaps the most typical application of the HSBP would be to perform a "snapshot" survey of a stream sub-unit in order to obtain baseline data for assessing overall quality and/or the degree of degradation due to human activities such as point source/non-point source pollution, stream-dewatering, construction adjacent to streams, ungulate grazing in riparian zones, etc. Application of the HSBP to a reach of lower Puali Stream in the Niumalu area of south-eastern Kauai (6/98), for example, revealed "poor" biotic quality as alien prawns and poeciliid fishes dominated the aquatic community to the near exclusion of native species (Fig. 6). The habitat metrics indicated

"non supporting" habitat for native aquatic macrofauna because of severe sedimentation, some dewatering, moderate bank erosion, and human-induced impact to the riparian zones. For stream assessment application, therefore, the HSBP provides a standardized means of comparing biotic integrity and habitat quality quickly and efficiently.

Impact Assessment

It may be necessary to evaluate the impact of an existing or proposed activity on a stream sub-unit which might include, for example, water diversion, dam construction, waste discharge, cattle grazing, etc. The basic study plan would involve comparisons of control vs. impacted site(s). The specific experimental design may be modified depending upon the level of replication required, the specific activity of interest and the physical conditions existing at the site. For example, the effect of an existing instream diversion can be studied by applying the HSBP directly above and below the diversion structure or at various distances from the structure over time. Control sites may also be established on adjacent streams in similar habitat and at similar elevations if suitable within-stream study sites are not available.

To demonstrate this application, two sites on Limahuli Stream, were evaluated for the impact of a highway crossing and diversion intake. One site was chosen above (35 m elevation) and one below (20 m elevation) the structures. Data generated by the HSBP indicated compromised stream biotic integrity in the reach below the highway crossing / diversion (Fig. 6); however examination of the habitat assessment data at the channel-unit scale indicated that most of the visible degradation to the stream was concentrated in the lowest reach quadrant. In this area a private landowner had removed riparian vegetation and graded areas adjacent to the stream resulting in soil loss from the bank. The stream bottom in this area was heavily sedimented and native macrofaunal species were entirely absent. Degradation in just two channel units, therefore, resulted in the lowering of the overall HS-IBI value for the site (Fig. 6).

Long-term Monitoring

Repeated application of the HSBP to appropriately identified stream study sites provides a very simple and highly standardized method for monitoring their physical and biological condition over time. Since both environmental and biological attributes are assessed in the HSBP, monitoring applications would provide information on long-term change occurring in both the native species assemblage as well as their supporting habitat. In addition, channel-unit scale information is provided as to the direction and level of human disturbance to the stream environment over time. These are key aspects to consider and include in stream restoration projects, instream-use application decisions, chemical spill monitoring, etc. The general level of resolution provided by the HSBP (Version 3.01) is probably most appropriate for annual or biannual monitoring application; however, the sensitive species metrics may be able to detect change occurring on shorter time-scales. The HSBP will be improved when algal and/or invertebrate metrics are developed which may be more sensitive to short time-scale changes.

Statewide Assessment of Streams

Application of the HSBP to streams on a statewide scale is a logical extension of its use and provides a standardized approach for efficiently and rapidly assessing the status of Hawaii's streams. A minimalist approach to performing a within-stream system assessment would be to select sites at various elevations from mouth to high-elevation midreach but only in the main channel. The number of sites selected, of course, would depend upon the size of the stream but should target, as a minimum, lower ($\leq$ 4 % slope), middle (5 % to 30 % slope), and high elevation (> 30 % slope) segments. Data obtained from these representative sites would be used to extrapolate biotic and habitat quality to encompass the entire stream. To date, the HSBP has been applied in 19 streams on all the major islands, 8 of which were sampled at multiple elevations and times (Fig. 5). These results substantiate the HSBP's usefulness in evaluating Hawaiian stream biotic integrity and related habitat quality
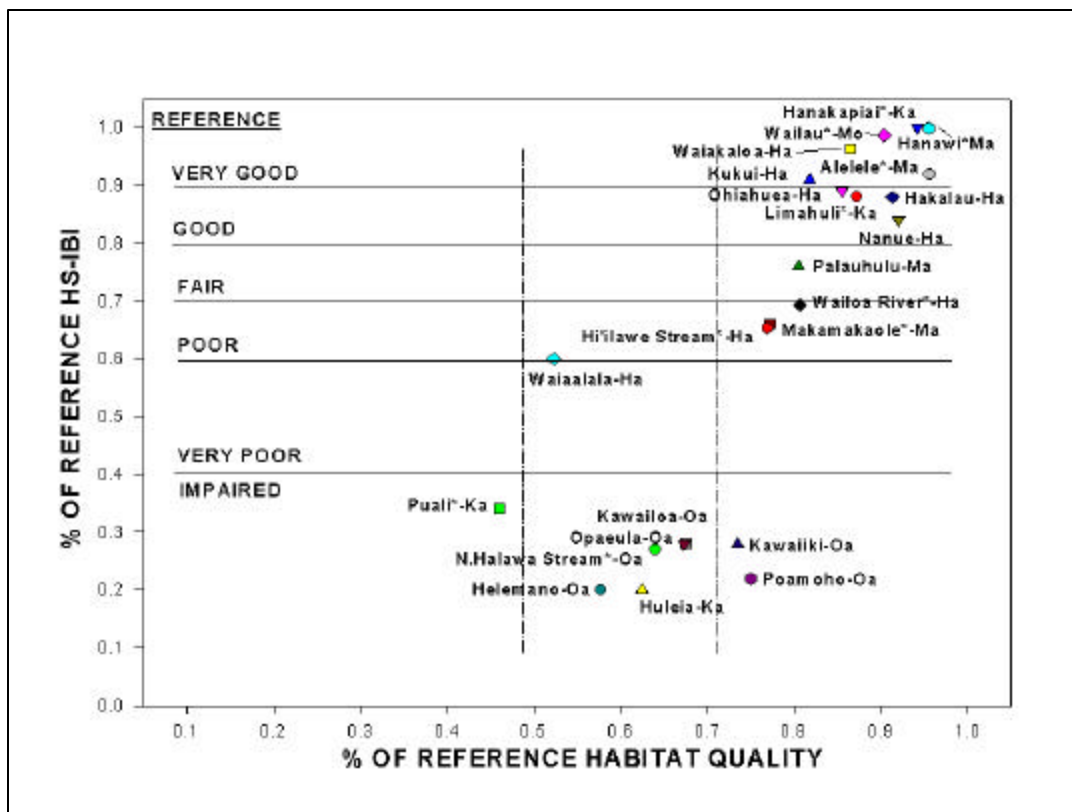

Figure 7. Comparisons of statewide stream biotic integrity (HS-IBI) vs supporting habitat quality as of January 2002 (*averaged values in streams sampled at multiple elevations / times; Ka = Kauai, Oa = Oahu, Mo = Molokai, Ma = Maui, Ha = Hawaii).

The HSBP, therefore, provides a manageable data collection and informational framework for conducting a statewide assessment of Hawaii's streams. The last such inventory occurred over twenty years ago and concentrated primarily on areas near stream mouths (Timbol and Maciolek 1978). The logistical approach adopted for such an ambitious program will depend upon many factors including the level of available fiscal resources, adaptability of existing stream survey data, selection of the lead agency, etc. Perhaps the most logical and cost effective approach would involve a cooperative effort involving State and Federal agencies with jurisdictional

responsibilities related to streams. Standardized use of the GIS-ready Excel 2000 spreadsheet supplied with this CD-ROM would insure the applicability of the data for planning and management purposes.

GIS Application for the HSBP

The Geographical Information System (GIS) is a powerful data organizing and analyses tool that allows for the visualization of spatial data over a topographical base "layer" (most commonly a USGS quad map). "Layers" or "coverages" are created from field data which may be point locations of endangered species, polygons delineating area coverages like land-use boundaries, etc. Multiple layers may be overlaid depending upon the analyses and questions being asked of the data. The Hawaii Stream Assessment GIS Layer (Kido and Khan 1998) was developed with this use in mind.
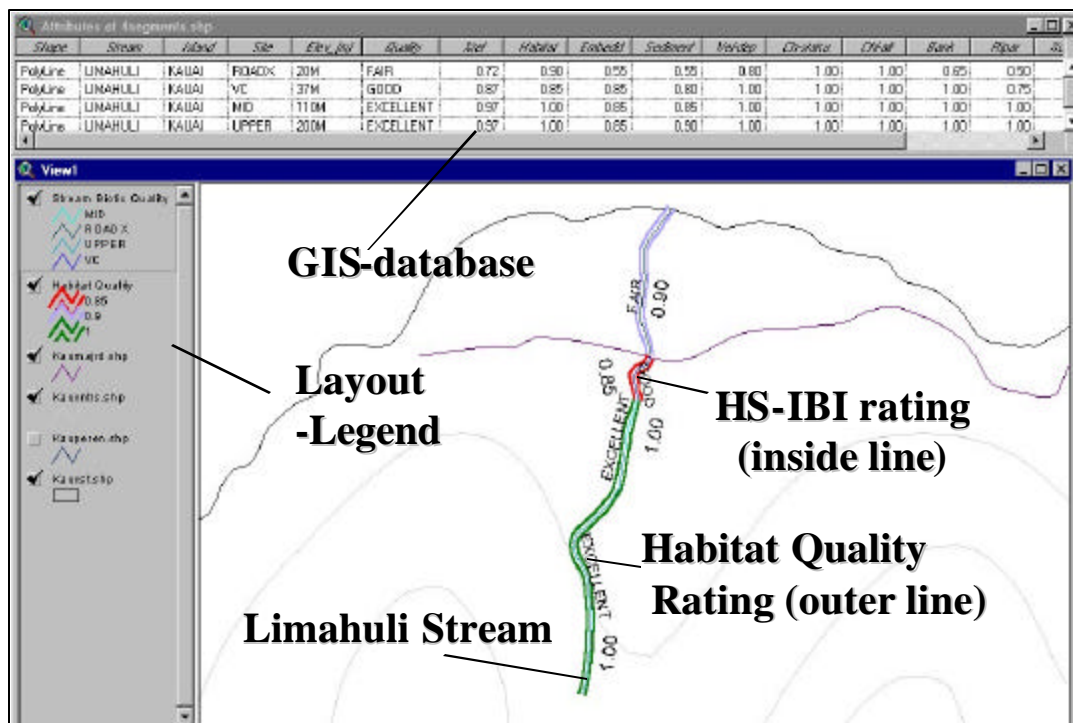

Figure 8. Arcview GIS layout of color-coded system for displaying HSBP data.

The rating system of the HS-IBI is designed for use in the GIS and will allow the user to separate streams by their biotic and habitat quality ratings. For example, all "excellent" streams may be colored in red, "good" streams in blue, "fair" streams in yellow, etc. By over-laying other available data layers (e.g. land use, vegetation, diversion locations, etc.) many kinds of useful analyses can be accomplished relatively easily. Photos, video, and other useful imagery taken at study sites can be easily linked to the GIS database providing a permanent visual record of existing conditions. Such a system allows managers to quickly access field-based stream quality information from their desktop computers. As satellite and infrared imagery becomes available for Hawaii, the GIS will become an increasingly sophisticated, "high-tech" tool for water resource management application.

QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance (QA) refers to the integrated program that ensures the reliability of quantitative and qualitative data that are collected and analyzed within the scope of a project. Quality control (QC) refers to specific features of a procedure that are intended to maintain certain standards of performance in each step of the data collection and management process. The integrated QA program for the HSBP is a continuous process implemented during field data collection / processing, laboratory analyses, and reporting results. Numerous documents outline QA / QC procedures (eg. Klemm et al.1993), and generic procedures specifically designed for stream bioassessment work have been developed (e.g. USEPA 1992).

Six qualitative and quantitative data characteristics are employed to describe data quality:

- Precision - The level of agreement among repeated measurements of the same characteristic.
- Accuracy - The level of agreement between the "true" and the measured value.
- Representativeness - The degree to which the collected data accurately reflect the true system of population.
- Completeness - The amount of data collected compared to the amount required under ideal conditions.
- Comparability - The degree to which data from one source can be compared to other similar sources.
- Measurability - The degree to which measured data exceed the detection limits of the analytical methods employed.

Quality Assurance (QA)

QA begins with the competence of the project personnel. A trained aquatic biologist, with in depth knowledge specific to Hawaiian streams, should function as the project lead. All field personnel must be given adequate training to be able to generate data that are of high quality with regard to the characteristics identified above. In assessments of habitat quality, the HSBP has been designed to reduce observer bias during the evaluation process with reliance on measurement as opposed to subjective decision-making. The biotic metrics, however, rely upon the observer's ability to identify aquatic macrofaunal species and estimate their sizes underwater. It is essential, therefore, that a rigorous training program be instituted during which personnel are allowed to practice measuring objects of known length lying on the stream bottom as well as view stream organisms *in situ*. Data obtained by personnel during training exercises can be statistically compared to data from experienced divers. Personnel should also be adequately equipped with full-length wetsuits as they will have to remain submerged in 17°-20° water for at lest 60 minutes. Physical discomfort during the UVC procedure will definitely compromise the quality of the data generated.

Quality Control (QC)

QC efforts are supported by strict adherence to HSBP procedures that are repeated for each 25 % sub-unit of the study reach. Datasheets are designed to prompt the observer for subsequent steps required in the protocol. An annotated step-wise outline of the protocol is printed on the

back of the datasheet which is designed to be readily visible by simply flipping over the writing slate. The observer is also required to check-off the metrics assessed as well as sign / date the datasheet upon completion of the site work. These steps are intended to ensure that all required data is collected before leaving the study site and also provides a point of contact for the site assessment work should questions arise.

Instruments used in the executing the HSBP should be calibrated according to manufacture's instructions paying special attention to their routine use. Flow meters are calibrated differently depending upon make but should be re-calibrated on a quarterly basis as a minimum. Electronic devices are particularly problem prone when used in stream environments because of constant high humidity and frequent exposure to water from rain or splashed from the stream. Meter readings that appear abnormal or out of expected ranges should be verified through a calibration procedure (preferably before going out into the field). Technical familiarity with equipment used is extremely important to ensure the accuracy and precision of data generated in the field.

LITERATURE CITED

Allan, J. D. 1996. Stream Ecology: Structure and function of running waters. Chapman and Hall, New York.

Allen T. F. H. and T. B. Starr. 1982. Hierarchy: perspectives for ecological complexisty. University of Chicago, Chicago.

Baker, J. A. and S. A. Foster. 1992. Estimating density and abundance of endemic fishes in Hawaiian streams. Report to the Hawaii Division of Aquatic Resources, May 1993.

Barbour, M. and J. R. Karr. 1996. Biological Criteria: Technical guidance for streams and small rivers. U.S. EPA 822-B-96-001, May 1996.

Barbour, M. T., J. G. Gerritsen, B. D. Snyder, J. B. Stribling. 1997. Rapid bioassessment protocols for use in streams and rivers: Periphyton, benthic macroinvertebrates, and fish. EPA 841-D-97-002. Draft Revision, July 29, 1997.

Clausen, B. and B.J. F. Briggs. 1997. Relationships between benthic biota and hydrological indices in New Zealand streams. Fresh. Biol. 38:327-342.

Cummins, K. W. 1962. An evaluation of some techniques for the collection and analysis of benthic samples with special emphasis on lotic waters. Amer. Midland Naturalist 67:477-504.

Devick, W. S. 1991. Patterns of introductions of aquatic organisms to Hawaiian freshwater habitats. Pg189-213. *In* W. S. Devick, ed. New Directions in Research, Management and Conservation of Hawaiian Freshwater Stream Ecosystems. December 1991.

Font, W. F. and D. C. Tate. 1994. Helminth parasites of native Hawaiian freshwater fishes: An example of extreme ecological isolation. J. Parasitol. 80(5): 682-688.

Ha, P. Y. and R. A. Kinzie III. 1996. Reproductive biology of, *Awaous guamensis*, an amphidromous Hawaiian goby. Environ. Biol. Fish. 45:383-396.

Hamilton, A. L. and O. A. Saether. 1971. The occurrence of characteristics deformities in the chironomid larvae of several Canadian lakes. Can. Entomol. 103: 363-368.

Hawaii Stream Assessment. 1990. A preliminary appraisal of Hawaii's stream resources. Report R84, Hawaii Commission on Water Resource Management, Honolulu, Hawaii, December 1990.

Hawkins, C. P., J. L. Kershner, P. A. Bisson, M. D. Bryant, L. M. Decker, S. V. Gregory, D. A. McCullough, C. K. Overton, G. H. Reeves, R. J. Steedman, and M. K. Young. A hierarchical approach to classifying stream habitat features. Fisheries 18 (6): 3-12.

Hilsenhoff, W. F. 1987. An improved biotic index of organic stream pollution. Great Lakes Entomol. 20:31-39.

Karr, J. R. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21-27.

Karr, J. R. and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environ. Manage. 5:55-68.

Karr, J. R. , K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessing the biological integrity in running waters: A method and its rationale. Illinois Natural History Survey, Special Publication 5, September 1986.

Karr, J. R. and E. W. Chu. 1997. Biological monitoring and assessment: Using multimetric idexes effectively. EPA 235-R97-001.

Kerans, B. L. and J. R. Karr. 1994. A benthic index of biological integrity (B-IBI) for rivers of the Tennessee Valley. Ecol. Appl. 4:768-785.

Kido, M.H. and M.A. Khan. 1998. GIS Adaptation of the Hawaii Stream Assessment. Report to the U.S. Fish and Wildlife Service, Pacific Islands Ecoregion, Honolulu, Hawaii. January 1998.

Kido, M.H., D.E. Heacock, and A.M. Brasher. 1994. Comparison of visual estimation methods applied in Hawaiian streams. In: *Proceedings of the International Symposium on Hawaiian Stream Ecology, Preservation and Management,* 1993 Hilo, Hawaii, C.M. Way (ed.). U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

Kido, M.H., P. Tamaru, R. Kinzie. 1993. Insect introductions and diet changes in the endemic Hawaiian amphidromous goby, *Awaous stamineus* (Edouyx and Souleyet)(Pisces:Gobiidae). Pac.Sci. 47(1):43-50.

Kido, M.H. 1996a. Diet and food selection in the endemic Hawaiian amphidromous goby, *Sicyopterus stimpsoni* (Pisces: Gobiidae). Environ.Biol.Fish. 45(2):199-209.

Kido, M.H. 1996b. Morphological variation in feeding traits of native Hawaiian stream fishes. Pac.Sci. 50(2):184-193

Kido, M.H. 1996c. Recovery Processes in Hawaiian Streams. In: *Proceedings of the Hawaii Stream Restoration Symposium*, *1994, Honolulu, Hawaii, Technical Report 96-01*, W.Devick (ed.), State Department of Land and Natural Resources, Aquatic Resources Division.

Kido, M.H. 1997a. Food relations and coexistence between native Hawaiian stream fishes. Env.Biol.Fish. 49:481-494.

Kido, M.H. 1999. The River Continuum Concept and watershed-scale patterns in community structure, ecological function, and hydrology of Limahuli Stream, Haena, Kauai. Report to the Division of Aquatic Resources (Hawaii Department of Land and Natural Resources) and Limahuli Garden (The National Tropical Botanical Garden). November 1999.

Kinzie, R. A. III. 1990. Amphidromous macrofauna of Hawaiian island streams. Species profiles: Life histories and environmental requirements of coastal vertebrates and invertebrates Pacific Ocean Region. Report 3. Technical Report EL-89-10. U.S. Army Corp of Engineers, August 1990.

Klemm, D. J., Q. L. Strober and J. M. Lazorchak. 1993. Fish field and laboratory methods for evaluating the biological integrity of surface waters. EPA/600/R-92/111. Biological monitoring of aquatic systems. Lewis Publishers, Boca Raton.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. Freeman, San Francisco, CA.

Ludwig, J. A. and J. F. Reynolds. 1988. Statistical Ecology. John Wiley & Sons, New York.

Lyons, J. , L. Wang. , and T. D. Sinonson. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. N. Am. Journ. Fish. Manage. 16:241-256.

Osborne, L.L. B. Dickson, M. Ebbers, R. Ford, J. Lyons, D. Kline, E. Rankin, D. Ross, R. Sauer, P. Seelbach, C. Speas, T. Stefanavage, J. Waite, and S. Walker. 1991. Stream habitat assessment programs in states of the AFS North Central Division. Fisheries 16(3): 28-35.

Polhemus, D. A., J. Maciolek, J. Ford. 1992. An ecosystem classification of inland waters for the tropical Pacific Islands. Micronesica 25(2): 155-173.

Rosgen, D. R. 1994. A classification of natural rivers. CAETENA 22:169-199.

Timbol, A. S. and J. A. Maciolek. 1978. Stream channel modification in Hawaii: Part A: Statewide inventory of streams; Habitat factors and associated biota. FWS/OBS-78/16. April 1978.

U.S. Government Printing Office. 1988. The Clean Water Act as amended by the Water Quality Act of 1987. Public Law 100-4. Washington, D.C.

USEPA. 1992. Generic quality assurance project plan guidance for bioassessment / biomonitoring programs. Office of Research and Development. U.S. Environmental Protection Office, Washington D.C.

Way, C. M., A. J. Burky, J. M. Harding, S. Hau, and W. K. C. Puleloa. 1998. Reproductive biology of the endemic goby, *Lentipes concolor*, from the Makamaka'ole Stream, Maui and Waikolu Stream, Molokai. Environ. Biol. Fish. 51:53-65.